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14. ABSTRACT
The objective of this study was to support the USMC Expeditionary Energy Office (E2O) with the development of a transparent and repeatable analytical process for measuring energy savings of proposed equipment purchases in the context of a fielded equipment list. The tasks defined an exploratory effort to 1) examine the energy consumption of environmental control units (ECUs) that provide heating and cooling to deployed Marine forces and facilities and 2) establish the significance of this consumption in the context of theater-level operations.
The Study Team decided to model the entire system in order to put ECU consumption in context. However, rather than look at fuel consumption from the supply side, the Study Team recognized it needed to build energy consumption from the bottom up in order to generate the necessary model fidelity and insight. Fuel usage was determined via the product of the fielded inventory of systems, system employment rates, and fuel or energy pull rate.
As the study proceeded and the scope and scale of the analysis became apparent, the Study Team formalized the methodology and

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Expeditionary Energy Office

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Abstract

The objective of this study was to support the USMC Expeditionary Energy Office (E2O) with the development of a transparent and repeatable analytical process for measuring energy savings of proposed equipment purchases in the context of a fielded equipment list. The tasks defined an exploratory effort to 1) examine the energy consumption of environmental control units (ECUs) that provide heating and cooling to deployed Marine forces and facilities and 2) establish the significance of this consumption in the context of theater-level operations.

The Study Team decided to model the entire system in order to put ECU consumption in context. However, rather than look at fuel consumption from the supply side, the Study Team recognized it needed to build energy consumption from the bottom up in order to generate the necessary model fidelity and insight. Fuel usage was determined via the product of the fielded inventory of systems, system employment rates, and fuel or energy pull rate.

As the study proceeded and the scope and scale of the analysis became apparent, the Study Team formalized the methodology and created the Marine Air-Ground Task Force (MAGTF) Power and Energy Model (MPEM). The study approach modeled a base case using the equipment and energy footprint of the Marine Expeditionary Force (MEF) Forward (FWD) in Afghanistan and four alternative cases to examine the impact of improvements in energy (fuel) consumed to maintain desired temperatures. Three excursions were conducted over a range of energy efficiencies – 10%, 20% and 30% - compared with the existing baseline ECU suite. A fourth excursion examined an alternative energy case where the existing baseline ECU suite was augmented with solar-powered ECU systems.

The study established that sufficient data was available to support the quantitative modeling of energy consumption at the theater level. MPEM energy usage results for the base case were compared to reported actual usage and agreed to the degree necessary to provide face validation. Additionally, MPEM base case results established that ECUs were significant consumers of energy in a theater context. MPEM results for the alternative cases suggested that potential savings from gaining efficiencies in existing ECU systems or augmenting them with solar-powered systems are worth further examination.

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Executive Summary

S1 *Background*

On 13 August 2009, the Commandant of the Marine Corps (CMC) declared energy conservation as a top priority. In October 2009, the United States Marine Corps (USMC) Expeditionary Energy Office (E2O) was created to "analyze, develop, and direct the Marine Corps' energy strategy in order to optimize expeditionary capabilities across all war fighting functions." The E2O also has a responsibility to "advise the Marine Requirements Oversight Council (MROC) on all energy and resource related requirements, acquisitions, and programmatic decisions."

S2 *Objective and Purpose*

The objective of this study is to support the E2O with the development of a transparent and repeatable analytical process that will measure the energy requirements of a given list of equipment.

The purpose of this study is to establish the impact of specific energy efficiencies on the larger energy-related footprint of USMC operations.

S3 *Tasks*

This study followed a task-oriented approach. Task 1 was to conduct a literature search, in order to build an understanding of the energy domain space. Task 2 was to develop data. In order to do this, the Study Team worked with six different organizations and incorporated seven principle data sets. Task 3 was to develop a methodology. In order to compute theater-level fuel usage, the Study Team developed a general, transparent and repeatable process of energy consumers in theater that incorporated three major categories: aviation, vehicles, and electric. Task 4 was to conduct an Interim Progress Review (IPR). Two IPRs were conducted in support of this study. Task 5 was to publish a draft and final report. This document constitutes the final report.

S4 *Methodology*

The literature review revealed that the Marine Corps has a good understanding of fuel consumption from a top-down, or "push" point of view. In other words, the supply-side of the equation is clear. The following are less clear: exactly how fuel is being consumed, the systems and rates of consumption, and how conditions modify consumption. Though a supply-side perspective is sufficiently granular to answer many questions asked by Marine Corps leadership, this study envisioned a more detailed understanding of the fuel and electrical demands of each deployed Principal End Item (PEI). Accordingly, this analysis breaks from the traditional supply-oriented view of in-theater fuel consumption by devising an enumerative process to calculate the energy demands of each PEI while accounting for factors that may affect that demand. In doing so, the study obtained a greater degree of fidelity by capturing effects such as the impact of ambient temperature on ECU electrical demand, and the impact of solar irradiation on solar-powered systems. The study evolved to conceive and develop a model that would offer the advantages of transparency and accuracy in the immediate effort and be adaptable to support future energy-related questions.

The Study Team built the Marine Air-Ground Task Force (MAGTF) Power and Energy Model (MPEM), a Visual Basic for Applications (VBA)-based tool. MPEM provides a greatly improved understanding of energy needs by examining both direct liquid fuel consumption by vehicles and other ground and air systems with gas or diesel

engines, and the fuel consumption associated with generators used for powering electrical items such as ECUs. While MPEM was primarily designed to support this study by automating the large number of calculations required to establish a theater-level demand portrait, it is a powerful tool that can model the energy needed to operate virtually any set of military equipment. For example, MPEM can assist unit logisticians in planning exercise fuel usage or analyzing Days Of Supply (DOS). Additionally, it can help acquisition professionals assess the impact new equipment will have on battlefield energy consumption.

The Study Team developed a matrix-based analysis plan to ensure that the factors affecting ECU demand (such as time of year) were varied. A base case, designed around the Marine Expeditionary Force (MEF) Forward (FWD) Equipment Density List (EDL) and current ECU suite, was run in MPEM for each factor. The Study Team then examined four alternative cases using MPEM to calculate the impact on energy use as measured in fuel tanker equivalents. Three of the alternatives postulated a more efficient current ECU suite that required less electricity to provide the same cooling capacity. The postulated efficiency improvements were 10%, 20% and 30%. The fourth alternative examined potential reductions in fuel demand resulting from the augmentation of the currently fielded ECU suite with systems that provide additional cooling capacity through solar-powered ECUs.

This report presents the results of the study from several perspectives to provide Marine leadership with a thorough understanding of the current theater-level power demands of forward-deployed forces in a combat environment and the impact each alternative would have on those demands. For example, the impact ECUs that are more efficient would have on energy demand is presented at several key points in the year to reveal how ambient temperature affects fuel demand. Results are then calculated over an entire year to present a fuller picture.

S5 ***Results***

A summary of the results from this study is shown in the table below.

	Savings in Tankers and Dollars, Aviation Loads			
	10% ECUs	20% ECUs	30% ECUs	Solar ECUs
Annual Savings, Tankers of Fuel	**79**	**158**	**217**	**487**
Annual Savings, Dollars (Millions)	**$2.42**	**$4.85**	**$6.65**	**$14.95**
Additional Load (C-17s / C-5s)	**n/a**	**n/a**	**n/a**	**37 /19**

Table 1-1: Annual Fuel Savings in Tankers and Dollars, Aviation Loads

The savings in dollars are calculated based on an operational cost for fuel at $6.39 per gallon.[1] The study was not scoped to research and document the technical challenges and associated costs of realizing the postulated efficiency gains of the alternatives. As such, the reported cost savings do not reflect the potential for a net return or loss on investment in the development and fielding of the alternatives. However, anecdotal evidence provided to the Study Team by the E2O suggests that:

- a 10% increase in efficiency from the current ECU suite requires only a nominal investment to achieve this level of efficiency and the gain is technically feasible;
- a 20% increase in efficiency from the current ECU suite would likely require a sizeable investment to overcome the associated technical hurdles; and
- a 30% increase in efficiency from the current ECU suite would certainly involve significant costs and might not be technically feasible.
- The augmentation of the current ECU suite by solar-powered systems obviously entails costs to purchase, deploy, operate, and maintain additional systems.

S6 *Conclusions*

Given the current cost of fuel, there is a clear implication for USMC savings with increased ECU efficiency in Afghanistan. The technological feasibility of the ECU efficiencies that can be achieved is unclear. Further exploration will be required to balance savings against investment. Any projected savings will vary based on scenario and theater. Although there are significant potential savings associated with the implementation of solar-powered ECUs in Afghanistan, this must be weighed against other operational costs. This includes increased transportation to deploy and either redeploy or transition in-country, as well as account for, an increased footprint on bases where solar panels are employed.

MPEM is face validated. It could be used to examine other aspects of the USMC energy footprint and consumption.

[1] Towards Developing "Fully Burdened Costs", Randal T. Cole, Edward R. Blankenship (HQMC P&R, PA&E) CIM D0021776.A1 January 2010, CNA

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1 Study Overview

This chapter explains the motivation for the study, the study goals, and provides general information addressing various administrative and academic matters.

1.1 Background

Energy needs have a significant impact on military operations. The costs associated with providing for the energy demands of the war fighter extend beyond the financial burden of providing liquid fuels. Operationally, demands for liquid fuel pull personnel away from the fight to provide convoy protection and assist with distribution. Recognition of these costs has generated a Department of Defense (DOD)-wide movement toward more efficient energy usage. Service-level offices have been established and charged with finding solutions to the ever-increasing demand for battlefield energy.

On 13 August 2009, the CMC declared energy conservation a top priority for the Marine Corps. Subsequently, in October 2009 the USMC E2O was created to "analyze, develop, and direct the Marine Corps' energy strategy in order to optimize expeditionary capabilities across all war fighting functions." The E2O also has a responsibility to "advise the Marine Requirements Oversight Council (MROC) on all energy and resource related requirements acquisitions and programmatic decisions."

In September 2010, the E2O initiated this study to explore the impact equipment that is more efficient would have on battlefield fuel demands. The Study Team first examined the energy demand of a "base case" involving the energy requirements associated with the theater-level equipment footprint associated with the MEF in Afghanistan in 2010. Four alternative cases were compared with the base case. Three of the alternatives postulated a more efficient current ECU suite that required less electricity to provide the same cooling capacity. The postulated efficiency improvements were 10%, 20%, and 30%. The fourth alternative examined potential reductions in fuel demand resulting from the augmentation of the currently fielded ECU suite with systems that provide additional cooling capacity through solar-powered ECUs.

1.2 Study Objective and Purpose

This study focused on one area of battlefield energy use – climate control equipment – in hopes of understanding how related electrical demands can be reduced, thereby reducing the overall fuel demand of battlefield units. Results were provided in a manner intended to help the Marine Corps leadership understand the relative impact of potential efficiency improvements in one part of the energy picture and to help inform decision-makers as they strive to realize the Marine Corps' stated goal of a 50% improvement in operational efficiency on the battlefield.[2] This study provides an understanding of the impact ECUs that are more efficient will have on battlefield energy concerns and creates a methodology for assessing the impact that future solutions may have.

1.3 Scope

The scope of this study is to provide technical and analytic support to the E2O. The analysis focus is on providing quantitative insights on energy demand, specifically targeting ECU efficiencies'. The following constraints, limitations, and assumptions are a combination of those documented in the Study Plan and others that

[2] United States Marine Corps Expeditionary Energy Strategy and Implementation plan, pg. 21

the Study Team uncovered while conducting the effort. The Study Plan was submitted to the Study Sponsor on 17 Dec 2010 and approved on 31 Jan 2011. [Items drawn from the Study Plan are marked with an asterisk (*)].

1.3.1 Constraints

This analysis is confined to an examination of a currently fielded ECU system base case in Operation Enduring Freedom (OEF) compared with, 1) three more efficient ECU suites, and 2) a solar-powered ECU.*

1.3.2 Limitations

Anticipated limitations of this study included the availability of real-world data. In order to understand the context for this analysis, the Study Team needed to determine the energy consuming PEIs in OEF, their rate of usage, and their sustained draw of power.*

1.3.3 Assumptions

This study assumed that the real-world data elements as described in the Limitations existed and were available to the Study Team. Real-world data that does not exist was estimated.*

1.4 Tasks

The Study Plan contained the following tasks.

Task 1 - Literature Search: Conduct an extensive literature search and analysis to understand the energy-consuming context of fuel users (aviation, vehicles, generators) with OEF-based data.

Instead of looking at energy from the top-down supply-perspective, the Study Team determined energy usage from the bottom-up pull-angle. Using this "pull" perspective, the Study Team will be able to create a high-resolution view of how generator electricity is used, and the relative impact of any electrical consuming PEI.

Task 2 - Gather Data: Gather necessary data for, 1) a currently fielded ECU system, 2) an improved ECU system, and 3) an alternative energy system selected by the sponsor.

Data elements required included: on-hand quantities of PEI; sustained power draw rates; system employment rates; and hourly utilization rates. Where these data elements were unavailable, surrogates or estimates were employed and documented.

Task 3 - Develop a Process: Develop a transparent and repeatable analytical process that will measure energy savings of proposed equipment purchases.

An analysis of alternatives was conducted using the power systems identified in Task 2.

Task 4 - Conduct IPR: Develop Interim Progress Review (IPR) materials for Study Sponsor review.

Task 5 - Write Report: Write a draft and final study report.

This report documents the execution of the effort in task order.

2 Task 1: Literature Search

The Study Team conducted an extensive literature search to avoid the influence of any preconceptions about in-theater energy use and permit an objective attack of the problem. The Study Team set out to gain a complete understanding of the problem space by reviewing policy documents, examining other energy-related studies, and interviewing stakeholders who were interested in the outcome of this study. The results of this task are discussed in this section.

2.1 35th CMC, Commandant's Planning Guidance 2010

In this document, General Amos provides clear guidance to the Marine Corps regarding reducing dependence on energy in the battlefield:

"The future security environment requires a mindset geared toward increased energy efficiency and reduced consumption, thus allowing us to operate lighter and faster. We will aggressively continue our pioneering efforts in energy through our E2O, with goals of reduced energy demand in our platforms and systems, self sufficiency in our battlefield sustainment, and a reduced expeditionary foot print on the battlefield."

The Commandant goes on to provide specific tasks to the Expeditionary Energy Office: "…develop a plan to decrease the Marine Corps' dependence on fossil fuels in a deployed environment. Implementation of the plan shall begin during FY 11 and be fully funded in the POM 13 budget cycle. Concentrate on three major areas: (1) increase the use of renewable energy; (2) instilling an ethos of energy efficiency; (3) increase the efficiency of equipment. The objective is to allow Marines to travel lighter — with less — and move faster through the reduction in size and amount of equipment and the dependence on bulk supplies. (Due: 18 Feb 11)"

These two excerpts provided the Study Team with a clearer understanding of the direction and magnitude of the push within the Marine Corps to increase energy efficiency.

2.2 Reducing Energy Footprint on the Battlefield, Michael Bowes • Barry Pifer, CRM D0022638.A2/Final June 2010, Center for Naval Analyses (CNA)

This report indicates factors that drive energy concerns, points to solutions for reducing fuel use, and offers recommendations on addressing primary capability gaps at distributed operating bases. Supporting analyses were not included in this document, which only referenced them via various other reports. It offers a good overview of how energy is being consumed from an aggregate, supply-side perspective that helped frame the energy consumption context for the Study Team, but did not ultimately provide data or insight into the Study Team's analytical approach.

2.3 Fuel and Water for OEF, Towards Developing "Fully Burdened Costs", Randal T. Cole, Edward R. Blankenship (HQMC P&R, PA&E), January 2010, CNA

This report catalogs Fully Burdened Cost of Fuel (FBCF) and Fully Burdened Cost of Water (FBCW) findings from various studies, including:

- 2001 study from the Office of the Under Secretary of Defense for Acquisition, Technology & Logistics;

- 2006 study from the Army Environmental Policy Institute;
- 2008 Workshop from the National Defense Industrial Association FBCF; and
- Quick-turn OEF analysis from Defense Advanced Research Projects Agency for the CMC.

This report calculated the cost up through the first leg of tactical delivery, i.e., from the point of retail sale to the main camp to the Forward Operating Base (FOB), designated the Assured Delivery Price (ADP). This price is as the "operational level price" and given at $6.39 per gallon at Camp Dwyer.

2.4 Powering America's Economy: Energy Innovation at the Crossroads of National Security Challenges, July 2010, CNA

The questions addressed in this report concern: the key links between national security, energy, and the economy; the national security challenges and benefits of developing a clean energy economy in the United States; and how DOD can contribute to America's economic and national security while addressing its own energy challenges.

While this document provides important context for the overall energy conversation, the dialogue is largely strategic (e.g. "…DOD can propel the nation toward a clean energy economy, helping turn what could be a crisis into the next great American opportunity"), and as such is not directly applicable to this study.

2.5 Fully Burdened Cost of Fuel Methodology and Calculations for Ground Forces: Sustain the Mission Project (SMP) 2 NDIA Fully Burdened Cost of Fuel Workshop, Steve Siegel Energy and Security Group August 28, 2008, PowerPoint presentation

SMP I developed an analytic methodology in FY06 for calculating the fully-burdened costs of fuel resources to sustain Army missions in theaters of operation and the training base. SMP II built on SMP I for calculating the fully burdened costs of fuel and for evaluating energy technology investments.

SMP II determines the impact on fully burdened cost of fuel due to changes in input parameters and assumptions such as convoy miles (operational risk), convoy composition, force protection, and price of JP-8, but uses Army and DOD databases, metrics, and processes. These were not considered for this study as these considerations were out of scope.

2.6 Army Environmental Policy Institute Report, Sustain the Mission Project: Casualty Factors for Fuel and Water Resupply Convoys, Final Technical Report, September 2009

This study attempted to develop a methodology for calculating casualty factors for fuel and water resupply convoys in theater operations and to demonstrate the methodology based on historical data from OEF and Operation Iraqi Freedom (OIF). Casualties reflected Army soldiers and civilians killed or wounded while transporting fuel or drinking water to consuming units and forward operating bases in theater. This analysis builds on previous SMP analysis to estimate potential casualties avoided as a result of investment in energy and water technologies that could reduce the number of resupply convoys in theater.

While establishing the number of casualties may be straightforward (although deconflicting duplicate reported incidents can be challenging), establishing the actual number of Marine convoys is very difficult, because fuel can be delivered from a local contractor, the Army or the Marine Corps, and the Marine Corps does not have visibility on convoys outside of its control. Consequently, the Study Team did not use "potential casualties avoided" as a metric of this study.

2.7 Experimental Forward Operating Base (ExFOB) Power and Energy, Jim Lasswell Tech Director, 7 April 2010, PowerPoint presentation

This presentation notes the increasing demands for battery power and the historical (exponential) trend of increasing power demands. It also touches on many of the most common problems of utilizing energy in theater, to include generators operating at low power. This presentation focuses on optimizing FOB design and does not contain explicit analysis.

2.8 Future Squad Power Needs Study, Operations Analysis Division, Marine Corps Combat Development Command, August 2010

This study was nominated through the Marine Corps Study System in January 2009. It supports an analysis need expressed by the Office of Naval Research (ONR), Expeditionary Maneuver Warfare and Combating Terrorism Department. The analysis examines both current and future squad power demand. The study was performed to inform the development of a future squad-level power system architecture that would ensure power demands are met.

The study identifies squad power demands by dividing them into sets of tasks and procedures across multiple mission profiles. By comparing future demand with current demand, the study provides a better understanding of the implications of energy for the Marine Corps.

Information from this study was focused at a level that was not directly applicable to supporting the needs of the E2O study.

2.9 MAGTF Bulk Fuel Requirements Study, Operations Analysis Division (OAD), Marine Corps Combat Development Command (MCCDC), 13 August 2010

The Operations Analysis Division (OAD) Bulk Fuel Requirements Study (BFRS) describes how bulk fuel is delivered in a theater. The Study Team used multiple data elements from this study, including: Table of Authorized Material Control Number (TAMCN); quantity of fuel consumed for each TAMCN, in Gallons Per Hour (GPH); and the number of Hours Per Day (HPD) a TAMCN is in use. This data was available for all fuel consumers (not electrical energy consumers) used in the E2O study.

2.10 Report of the Afghanistan, Marine Energy Assessment Team (MEAT), December 2009, Released January 2011

This report is based on a MEAT visit to Helmand province in southern Afghanistan to identify measures to reduce the cost and risk of providing energy and water. The team visited a range of large and small bases, soliciting inputs from leadership, logistics staff and other concerned personnel, and collecting data onsite.

The MEAT report notes that water delivery places a significantly greater load on the logistics than fuel, especially at the tactical edge. It also notes practices that waste fuel, such as insufficient generator loading. The MEAT report offers several near-, mid- and far-term recommendations based on other analysis as well as the first-hand knowledge of this considerable pool of Subject Matter Experts (SMEs).

2.11 The Marine Corps Expeditionary Energy Strategy and Implementation Plan, 24 February 2011

This document, which was published near the end of the E2O effort, is comprehensive in that it includes the vision, mission, scope, goals, and initiatives for a way ahead for the Marine Corps to address issues associated with energy. It states that the energy goals for the Marine Corps are a 50% reduction in energy consumption, from 8 gallons of fuel/Marine/day to 4 gallons of fuel/Marine/day by 2025.

3 Task 2: Gather Data

This section explains how the Study Team approached identifying, acquiring, compiling and reconciling data from various sources. Subsections 3.1 through 3.7 document specific data sources and their contributions to this study. Sections 3.8 through 3.11 discuss the completeness of the data and address the Study Team's efforts to remedy or mitigate data irregularities and gaps.

3.1 Expeditionary Energy Office (E2O)

E2O served as both the sponsor and a source of data for this study. In addition to providing the aforementioned MEAT Afghanistan Assessment discussed in subsection 2.10, E2O made accessible two types of data to support this study: an EDL from OEF and real-world figures of in-theater liquid fuel consumption.

The EDL, dated 7 September 2010, contains the Unit Table of Equipment (T/E) Requirement (UTR) and on-hand quantities for the MEF deployed to Afghanistan in support of OEF. This list details specific quantities of TAMCN for each of the four elements of the MAGTF: Command Element (CE), Ground Combat Element (GCE), Air Combat Element (ACE), and Logistics Combat Element (LCE). The EDL provided by E2O served as the source of equipment covered by this study.

Consumption numbers reported from the MEF fuels officer from April to September 2010 (further discussed in subsection 4.7.4) served as a real-world baseline to which the study's calculated results (further discussed in section 5.1) could be compared.

The E2O differentiates fuel consumption by aviation, vehicles, and generators/electrical. This breakdown is useful to them because each category requires different energy densities. Aviation requires the highest energy densities, vehicles require a lesser energy density, and electrical a range of energy densities. Consequently, each of these categories requires a different energy efficiency strategy to be employed. See Section 5.1 for analysis using aviation, vehicles and electrical energy breakdowns.

3.2 Expeditionary Power Systems (EPS) Program Office

The EPS Program Office at Marine Corps Systems Command (MCSC) was an important source of information for ECUs and generators throughout this study. The staff familiarized the Study Team with expeditionary power production, helped to validate study assumptions, and provided valuable input throughout the analysis. They explained key concepts about ECUs and generators, discussed how they consume and convert power, and identified the factors (generator size, loading) that affect efficiency.

The Study Team's data exchanges with EPS revealed that generator efficiency is based on two main factors – generator size and the loading-to-capacity ratio. Generator efficiency is reduced under low loads. Most generators have an ideal loading of 75% to 85% of their capacity. Further, larger tactical quiet generators (TQG) that are optimally loaded are typically more efficient than smaller TQGs that are optimally loaded. Figure 3-1 below, provided by the EPS Program Office, illustrates these efficiency curves.

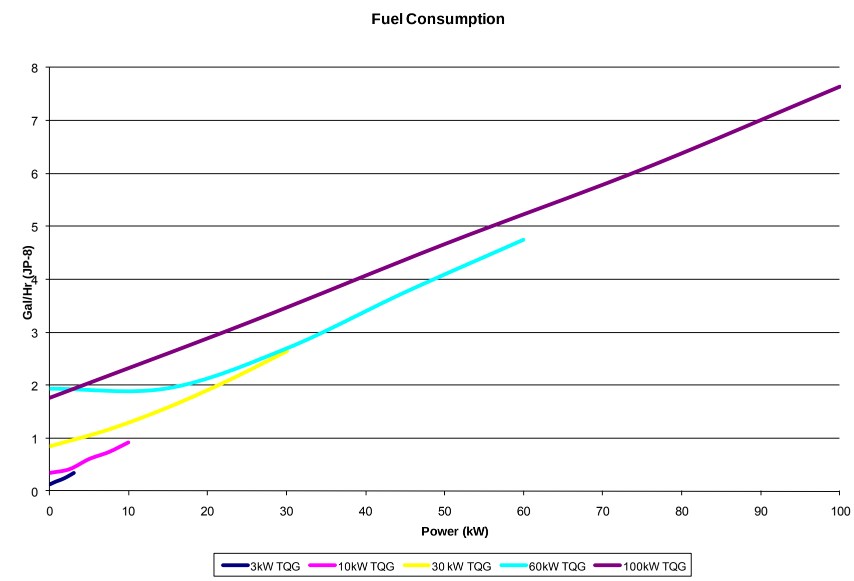

Figure 3-1: Generator Efficiency

The application of these efficiency curves in this study is covered in subsection 4-3 of this report.

3.3 OAD BFRS

The BFRS provided the Study Team with fuel consumption data in gallons per hour (GPH) for nearly all fuel-consuming items listed in the EDL and estimated usage rates, in hours per day (HPD), for each item. This data was generated using OIF-based assumptions but is considered by the BFRS Study Sponsor to be generic enough to be representative of the power requirements for OEF as well. The Study Team compared the consumption rates found in the BFRS to the fuel and electrical equivalent consumption rate found in Total Force Structure Management System (TFSMS) for accuracy. The Study Team also presented the usage data contained within the BFRS to the E2O office for validation. While this exercise generally found consumption rates and usage rates to be accurate, some discrepancies were identified. The Study Team's actions to address these for the purposes of the analysis are described below in subsection 3-10.

3.4 TFSMS

TFSMS served as the primary source of data for electrical power consumption rates. This study used peak power, expressed in kilowatts (kW). Although it would have been preferable to use a sustained power draw value, since a peak value is a short transient and does not provide an accurate summation over a sustained period of time, this state data is not available in TFSMS.

Though TFSMS is generally viewed as an authoritative source of data, the Study Team found several incorrect data elements. For example, TFSMS listed peak electrical draw as 60 kW for camera systems that clearly do not require such a large amount of power (see table 3-1). The Study Team suspects that the 60-Hertz frequency that most systems require might have been transposed into the wrong column in TFSMS. This and additional errors are described below in subsection 3.9. To resolve discrepancies, the Study Team compared TFSMS results with

other available data, consulted with MCSC documentation, and consulted vendor specifications. The Study Team's approach to consolidating data and mitigating errors is discussed further in subsections 3.8 and 3.10.

3.5 Army Materiel Systems Analysis Activity (AMSAA)

AMSAA provided further information beyond what was in the BFRS regarding vehicle fuel consumption and usage data, in particular data that addresses the amount of time a vehicle spends idling compared to the time spent moving. AMSAA generated these values via data-logging devices placed on Army vehicles deployed to OIF and OEF. This data is limited by sample size, as only a few types of vehicles and only a few vehicles within each type were instrumented, and several Marine-specific vehicles are not covered. However, when combined with the other sources of information, this data helped the Study Team refine its vehicle data to generate useful vehicle utilization trends.

3.6 Current Operations Analysis Support Team (COAST)

The Study Team met with the Director of COAST at OAD, MCCDC on three separate occasions to discuss fuel consumption in theater. COAST also afforded the Study Team the opportunity to review fuel storage data and reports directly from OEF. However, these reports, as well as other data that COAST was able to provide, only gave a snapshot into usage from a supply-side perspective. Once the Study Team recognized the limitation of supply-side data, COAST information became less applicable to this study and, ultimately, was not used.

3.7 SunDanzer

SunDanzer (http://www.sundanzer.com), a commercial firm based out of El Paso, produces a solar-based ECU system (not shown on their website) that served as this study's nominal basis for a solar-powered ECU that industry is capable of producing. Their solution employs solar panels to power a cooling-only ECU when sufficient sunlight is available – it does not utilize batteries for storage of excess power.

It is important to note that the selection of this system in no way represents an endorsement of SunDanzer or its products. This system and its demand characteristics were merely used as a surrogate for the alternative energy ECU system. From this point forward, this system shall be referred to as the "Solar Power ECU".

3.8 Data Consolidation

To capture the full portrait of energy consumption at a theater-level and provide context for understanding the implications of more efficient ECUs, the study required the compilation of data from multiple sources of information. To this end, the Study Team used the VLOOKUP function within the Microsoft Office Excel application, creating a spreadsheet to contain the deployed UTR and documented on-hand assets for the MEF deployed to Afghanistan. These inventories were captured at both the MAGTF level and the subordinate MAGTF elements (CE, GCE, ACE, LCE).

Descriptive data from the BFRS about specific PEIs that directly consume fuel detailed fuel consumption in GPH and usage data in HPD for the assault phase and sustained operations phase. Further, the data was not unit specific but HPD values did vary by phase and MAGTF element. The BFRS also provided background information on other non-vehicle fuel consuming items, such as electrical consuming items with their own built-in generator (lights, Integrated Trailer-ECU-Generator (ITEG)) that aided in refining and understanding fuel consumption rates.

TFSMS served as the initial source for electrical consumption data for generator-powered (i.e. electrical) equipment. The TFSMS data provided peak kW usage for most of the electrical powered items. TFSMS also provided fuel usage in GPH consumed, but this was not used as a primary source of energy consumption data due to perceived inaccuracies. (See subsection 3-10 for additional sources).

3.9 Data Quality

Most of the data elements the Study Team encountered were sound; however, there were significant shortcomings in the TFSMS GPH data elements. Table 3-1 provides a sample of some of the most egregious values in TFSMS, alongside with a reconciled alternative.

TFSMS Data Elements Comparison (GPH)				
TAMCN	**NOMENCLATURE**	**TFSMS Fuel GPH**	**Reconciled Alternative Fuel GPH**	**Reconciled Alternative Fuel Source**
A0116	SURVEY INSTRUMENT, AZIMUTH	40.95	0	Similar to PADS (Battery Powered)
A0170	COMM CENTRAL (TROJAN SPIRIT II)	40.6	8.6	Bulk Fuel Study
B0018	INTEGRATED TRAILER, ECU AND GENERATOR	17.5	2.2	Bulk Fuel Study
B0024	DISTRIBUTOR, WATER, TANK TYPE	56	6	Bulk Fuel Study
B0078	GRADER, ROAD, MOTORIZED	630	4	Equipment Brochure
B0160	ASSAULT BREACHER VEHICLE	420	60	Bulk Fuel Study
B0392	CONTAINER HANDLER, RT, KALMAR	420	9.5	Bulk Fuel Study
E0036	MARINE ARTILLERY SURVEY SET (MASS)	40.95	0	Similar to PADS (Battery Powered)
E1378	RECOVERY VEHICLE, FT, HEAVY, W/EQUIP (M88)	312.83	32.88	Bulk Fuel Study
E0950	LAV, MAINT/RECOVERY	69.72	11.01	Bulk Fuel Study

Table 3-1: Comparison of TFSMS and Alternate Source Data Elements

Since the study team had no way to determine which data elements in TFSMS were reliable, all data elements from TFSMS were reconciled against another source.

3.10 Mitigating Gaps in Power Data

As stated earlier in subsection 3.4, the Study Team discovered that one type of data was particularly challenging to gather. Specifically, data regarding the power requirements (not just volts, but volts times amps, or watts) of electrical equipment was frequently lacking in TFSMS, MCSC documentation, and industry-generated

information. This lack of data presented an obstacle to this study, and will have to be corrected if the Marine Corps is to gain a full understanding of electrical power consumption on the battlefield. This point is discussed further in Section 6 of this report.

The Study Team conducted an exhaustive process of information gathering to address this shortcoming through the technique of surrogation. First, the Study Team consulted available open-source data to gather as much information as possible for each electrical system for which data was missing. Once a complete understanding of the system was achieved, the Study Team identified a similar system for which the power (watts) value was known. For example, for a particular 110 Volt Alternating Current system for which power or current values were not provided in authoritative USMC sources, open-source information indicated that the system is composed of two laptop computers. The Study Team accordingly assumed that the power value could reasonably be construed to be twice that of a known single-laptop system and noted in the study data archive the use of the surrogate value and justification for the assumption.

The Study Team, via interviews with the Study Sponsor, developed assumptions regarding the Percent Equipment Operating (PEO) rates for various types of items. For instance, a "type" of item might be radars, or laptop computers. Two forms of data were collected during the interviews: the PEO and the hours per day (HPD).

Given the focus of the study on ECUs, the Study Team limited its data collection for aviation system (meaning fixed- and rotary-wing platforms) fuel requirements to an aggregate average amount of fuel used per month. This data was obtained from the MEF fuels officer from April to September 2010 as referenced in subsection 3.1.

3.11 Alternate Systems Selection

3.11.1 Increased Efficiency from ECUs

Both the EDL and discussions with MCSC, confirmed that the there is not one currently fielded ECU, but rather a suite of ECUs involving more than one system. During interviews, it was relayed to the Study Team that before the current suite of ECUs, there was no "off the shelf" suite of ECUs to select from, and PEI developers were free to create or borrow any ECU system in existence to fulfill their particular application. This approach, however, becomes problematic when it comes to training and maintenance – it is much more efficient and easier to maintain a standardized set of ECUs than "anything goes." Thus a suite of ECUs was created by MCSC from which developers are free to choose when a new PEI they are developing requires cooling.

Before the current suite of ECU's as shown in Figure 3-2, there were reliability problems with the ECUs, but reliability was eventually improved to 99.5% or better. Today, a lack of reliability is no longer an issue and the current suite of ECUs now has sufficient reliability. However, there are no efficiency standards associated with it. Consequently, manufacturers responded without considering efficiency, and this may be reflected in the lack of power consumption figures available as discussed in section 3.4 and 3.10.

Figure 3-2: Current Suite of ECUs

Initially, MCSC indicated that 15% efficiency seemed to MCSC to be a representative value of what is technologically possible to achieve without introducing changes to the basic ECU technology (e.g., a compressor). Consequently, the Study Team began the effort by examining the impact of a 15% increase in efficiency from the baseline ECU suite.

During the course of this study, this efficiency assessment was revised and given additional specificity. MCSC believed a 10% increase in efficiency from the existing suite of ECUs was technically achievable without significantly increasing the costs to the ECUs, and that a 20% increase in efficiency might also be technically possible, but at a much greater expense. Additional, MCSC believed a 30% increase in efficiency might not be technically possible given an unchanged form factor for the suite of ECUs. However, the Study Team thought there was utility in examining the general trend of efficiency potential independent of technological feasibility and cost resources. Consequently, this study was retooled to evaluate the impact of both efficiency increases of 10% and 20% and 30% efficiency alternatives.

3.11.2 The alternate energy system

The alternate energy system selected for inclusion in this study was based on a SunDanzer system, illustrated below in Figure 3-3.

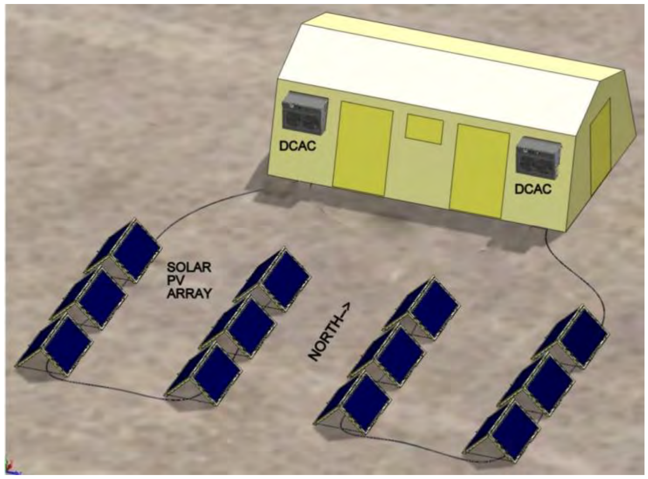

Figure 3-3: Solar-powered ECU Alternative

As seen in Figure 3-3, solar panels provide Direct Current (DC) power to the ECUs when the sunlight is available. Counter-intuitively, the solar panel design is not set up to face South (assuming deployment North of the equator). Instead, according to SunDanzer employment directions, they face East-West in order to maximize the time each day in which solar power is available. This approach, confirmed by SunDanzer's own data, generates less total power each day, but provides solar cooling that is available for a longer total period of time each day. The sunlight is less intense to the collectors and therefore the total power is less than a south-facing configuration, but the length of time that the solar-powered systems can run per day is longer.

In order to determine the number of solar-powered ECUs, the Study Team calculated the number of British Thermal Unit (BTU)s that could be generated by the base case suite of ECUs, in this case 1,784 AC-powered ECUs. The quantity of solar-powered ECUs required to generate equivalent BTUs was 1,422 solar-powered ECUs systems consisting of: 2,844 DC-powered ECUs (2 per system) and 17,064 solar panels (12 per system).

It is important to note that the selection of this system in no way represents an endorsement of SunDanzer, its product design and/or its operational configuration. This system and its demand characteristics were merely used as a surrogate for the alternative energy ECU system. From this point forward, this system shall be referred to as the "Solar Power ECU".

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4 Task 3: Develop a Methodology

Task 3 encompassed a majority of the study effort. While issued as a single task, it was executed by the Study Team in two discrete steps. This section addresses the development of the methodology, which describes the overall analytical approach and the evolution of the methods used to actually conduct the analysis and complete the study. In section 5, the second step of Task 3, the Study Team conducted the analysis and determined the results for this study.

4.1 Analytical Paradigm and Study Approach

The majority of energy data available to the Study Team was denominated in terms of fuel supplied or electrical generation capability. While this supply-side perspective reflected the fuel consumed at a MEF level or the power generated by a MEF, it did not enable determination of the impact of changes in energy consumption by individual PEIs. Given that the values for fuel used or electricity generated were at an aggregate level, changes in use could not be associated with individual PEIs. Given the energy used could not be attributed to individual PEIs, the effects of energy efficiency gains could likewise not be accounted for.

In face of the shortcomings of the supply-side approach for comparative analysis at the system level, the Study Team adopted an approach that embraced a demand-side perspective to account for the energy requirements at the PEI level. Having determined the energy demand at the PEI level and accumulated those demands up to the theater level, the aggregate impact of potential energy efficiencies (or any changes to energy consumption) to could be credibly and transparently calculated. These two opposing paradigms are shown below in Figure 4-1.

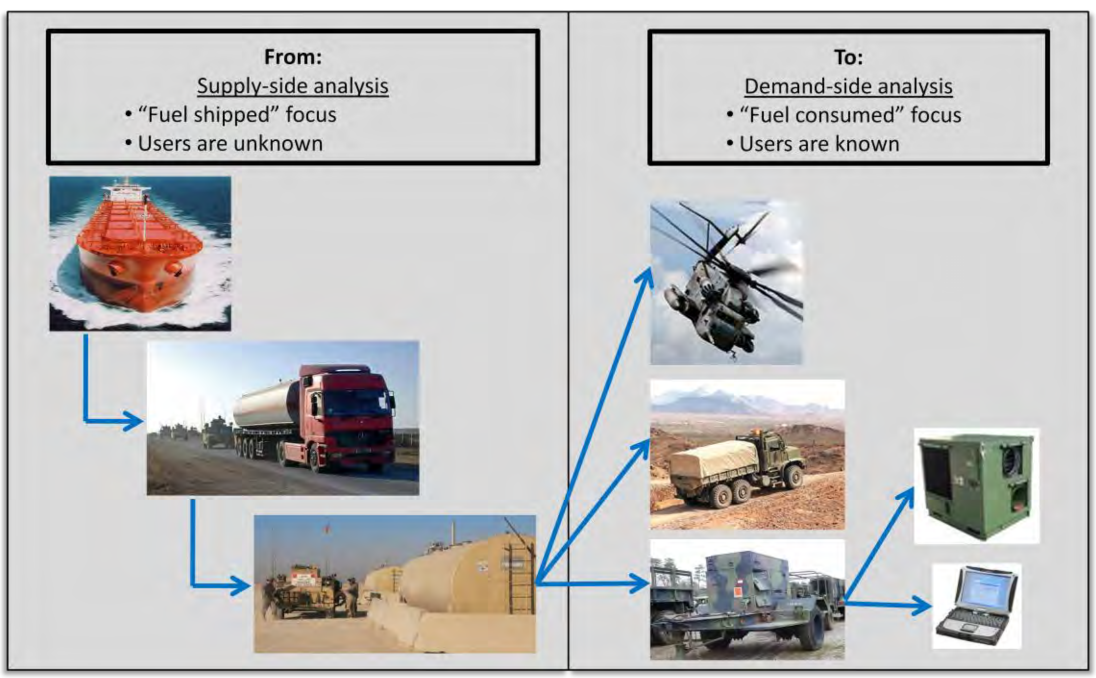

Figure 4-1: Paradigm Shift in Energy Related Analysis

4.2 Measure of Effectiveness (MOE)

The Study Team chose to denominate the impact of efficiency gains in ECU performance in terms of “fuel tanker equivalents.” This metric referred to savings in fuel consumed in terms of the number of MK970 fuel-dispensing semi-trailers used by the Marine Corps primarily for bulk fuel delivery. Although the MK970 holds 5000 gallons of fuel, this study operationalized that value to 4800 gallons to account for fuel remaining in the tank and lost in the tubes.[3] Secondary MOEs were the mobility impacts in airlift loads and employment considerations. They are discussed at the end of the section.

4.3 Data Manipulation and Assumptions

The demand-side methodology required accurate data describing the PEIs and associated conditions in theater to compute total fuel consumption. The Study Team used five primary data sources to develop the theater demand footprint as shown below:

- EDL, MEF (FWD), 7 Sep 10
- TFSMS[4]
- MCCDC/OAD BFR Study, 13 Aug 10[5]
- National Oceanic and Atmospheric Administration (NOAA) Climatic data
- MCSC system documentation

Additionally, Government- and contractor-generated system specification sheets were used to deconflict and verify data that was suspected as being incorrect.

During the initial IPR for this effort, several SMEs stated that ECUs are not the only system used for heating in OEF, and some units “outside of the wire” (meaning not in a base camp) use H-45 Heaters while ECU resistive heating is used “inside the wire”. The total quantity of H-45 (900) in the Area of Responsibility (AOR) was apportioned to the elements of the MAGTF in accordance with the proportion of ECU heating BTUs available within each of the MAGTF elements. The EDL, with the addition of the H-45 Heater was deemed the master inventory of items considered and analyzed in the study.

PEI electrical consumption rates were taken from the TFSMS database. These energy ratings were in kWs and were based on peak power draw. Continuous power ratings would have been more applicable to the study, given that peak power is usually attributed to equipment either first starting or under a heavy load. Nevertheless, peak power ratings were used for those PEIs in TFSMS because the continuous power ratings were not available.

To support the study’s primary MOE, fuel tanker equivalents, the energy consumptions described in kWs in TFSMS were converted into fuel GPH.

[3] MAGTF Bulk Fuel Study Final Report (29 October 2010)
[4] Total Force Structure Management System, Data pull
[5] MAGTF Bulk Fuel Study Final Report (29 October 2010)

This conversion of electrical energy usage (kWs) to liquid fuel energy usage was performed via a function based on energy conversion efficiency. The conversion function involved the theoretical BTUs generated from a kW of electricity, the theoretical BTUs generated from a gallon of diesel and generator efficiency. The equation is as follows:

$GPH = (kW * kW{\cdot}h_{BTUs} * (1.0/\text{Generator Efficiency})) / Diesel_{BTU}$

Where:

kW – kW rating of the PEI

$kW{\cdot}h_{BTU}$ – Theoretical BTUs from a kW of electricity, 3,412 BTU/h[6]

$Diesel_{BTU}$ – Theoretical BTUs from a gallon of diesel fuel, 138,700 BTU/h[7]

Generator Efficiency – Weighted efficiency of the on-hand generators in Afghanistan operating at 75% load

Usage rates for electrical systems were established according to conventions agreed upon at a data call meeting with the combined expertise of the E2O**.** An assumed 75% of the equipment was considered to be in-service (termed PEO). The remaining 25% was assumed either to be in maintenance or in reserve. Due to the practice of keeping a 1-to-1 backup generator in stand-by, 50% of the generators were assumed to be in use at any one time.

Vehicle fuel consumption rates and usage rates were taken from the BFRS, which denominated them in GPH. The usage rates were broken out by element of the MAGTF and by phase (Assault and Sustained) and denominated in HPD of use. The BFRS rates were primarily for vehicles and systems that directly consumed fuel. The fuel consumption rates, usage rates, and PEO were used to determine the vehicle fuel consumption.

The Study Team used Kandahar, Afghanistan ambient weather data sourced from NOAA. The average monthly high and low temperatures used in the model were based on the daily high and low temperatures from the NOAA data. The portion of an average day within a month that required heating and/or cooling was determined by comparing these monthly averages with the desired minimum and maximum temperature. This daily proportion of heating and cooling used for ECUs and H-45 heaters was driven by the ambient temperature.

For the purposes of this study, months were not centered on a traditional 15th, but instead were centered on the 21st of the month. Using the 21st allowed the solar equinoxes and solstices (which occur on the 21st) to be centered within a monthly period in order to capture the extremes of sunlight availability (max, min and two midpoints). Centering on the equinoxes and solstices was important to the solar aspect of this study as it provided minimum and maximum output for the winter and summer solstices respectively, as well as representative midpoints for the equinoxes.

[6] http://www.bts.gov/publications/national_transportation_statistics/2002/html/table_04_06.html
[7] http://www.bts.gov/publications/national_transportation_statistics/2002/html/table_04_06.html

4.4 Solar Data Sources

The productivity of the solar-powered ECU alternative is partially a function of a clear line of sight from its panels to the sun. Depending upon the latitude of the solar employment, the number of available hours of sunlight varies. Further, changes in the elevation of the sun associated with seasons also affect the intensity of the radiation provided to the solar panels; the sun must be at a sufficient elevation to irradiate the solar panels effectively.

The study assumed a deployment with a clear line of sight to the sun. The study also used Kandahar, Afghanistan as the location for determining solar angles, as a 10-degree elevation angle required to constitute the power rating necessary to minimally power the solar-powered ECU. Figure 4-2 below shows a Satellite Tool Kit (STK) calculation for the number of hours per day where the solar angle is greater than 10 degrees.

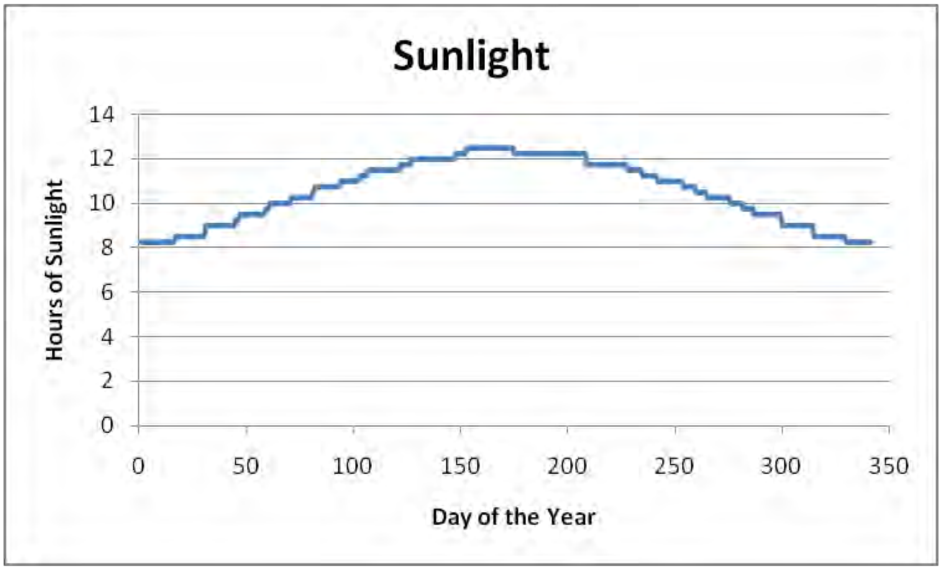

Figure 4-2: Daily Hours of Sun[8]

The sunrise and sunset times were used in concert with the ambient temperature to determine when cooling could be provided by the solar-powered ECUs. Figure 4-3 below shows a notional timeline of the three factors for a given day period.

[8] Satellite Tool Kit by AGI Inc

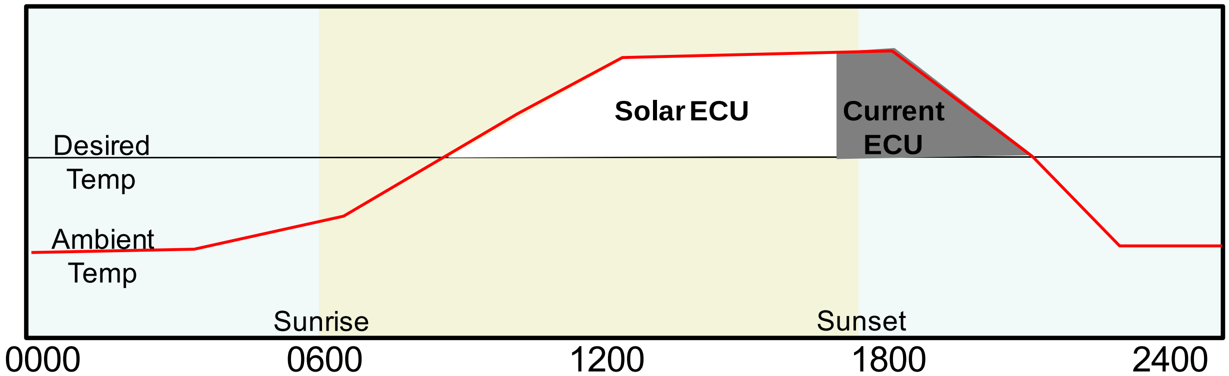

Figure 4-3: Notional Solar and Current ECU Employment Times

4.5 Aviation fuel usage

Aviation fuel usage as reported in this study was based on actual fuel consumption in the MEF (FWD) as reported[9] over 6 months from the fuels officer. An average monthly value was used for the aviation portion of the theater-level energy usage with the concurrence of the Study Sponsor given that aircraft fuel consumption was not the focus of the study and aviation fuel usage served only to complete the theater-wide energy picture in context with the vehicle and electrical fuel usage.

4.6 Evolution of Analytical Methodology

This subsection describes the methodology and calculations used initially in the study. The Study Team began by developing and presenting a proof of concept to the E2O to demonstrate the intended approach and methodology.

The analysis employed a demand-based calculation to determine the amount of fuel consumed and identify significant fuel consumers. This required fuel consumption rates, usage, and inventory for each of 621 TAMCN in the EDL. Total fuel consumption was computed as follows:

Fuel Used = ∑ (Qty TAMCN) (PEO) (HPD) (GPH)

Where: Qty TAMCN – TAMCN equipment quantities

PEO – Percent Equipment Operating

HPD – Hours per Day Equipment is used

GPH – Fuel consumption rate in Gallons per Hour

The values from the EDL, TFSMS, and BFRS were in spreadsheet formats that the Study Team manually imported into Excel. Additionally, the formulas were manually entered, summed, and pivot tables were created. This process provided initial information on the significant fuel consumers and demonstrated the utility of the concept. Already

[9] MEF fuels officer message, data from April to September 2010.

a labor-intensive process owing to the scale of the data involved, further time demands were imposed each time a formula was changed, data was refined or updated, or a new factor or constraint was added to the computation. Additional factors that affected the fuel consumption became apparent, which added to the complexity. These were:

- Impact of weather on temperature dependant PEIs
- Ability to easily update the data and recomputed the results
- Reduce errors and time to recompute the results

As the project grew in complexity, it became apparent to the Study Team that this approach was too manpower-intensive, prone to errors, and becoming impractical. Therefore, the Study Team championed, and the Study Sponsor sanctioned, the formulation of the data, assumptions and calculations into a formal model.

The MAGTF Power and Energy Model (MPEM) comprises 3,800 lines of executable VBA scripts. The model went through nine significant capability updates as new fuel considerations were understood and capabilities were required. The model as currently configured allows the following:

- adjusting the UTR or on-hand quantities from an EDL;
- in GPH or kW·h;
- summing the computing results for a variable number of days;
- selecting the month to use for temperature-dependent PEIs;
- updating inputs into the generator efficiency calculation;
- including vehicle idle and travel fuel consumption ratios; and
- allowing for further analysis expansion through normalized data importation and construction.

These improvements, in addition to a simpler user interface, not only benefited this study but offer enduring value to the Marine Corps for continued use.

4.7 MPEM Model Methodology

4.7.1 Calculations

This subsection describes the final methodology and calculations used in the study analysis and the factors used in the calculations. While the basic fuel consumption calculation described above was retained, other calculations increased in fidelity to consider additional factors such as weather, usage rates, vehicle usage, and hours of use per day associated with solar availability. Those factors and how they were calculated for each of three energy consumption categories – electrical, vehicle, and aviation systems – are described in the following paragraphs.

4.7.2 Electrical System Energy Calculations

Electrical fuel consumption was calculated as:

$$\text{Fuel Used} = \sum (\text{Qty TAMCN})(\text{PEO})(\text{HPD}_{\text{Cooling}})(\text{GPH}_{\text{Cooling}})(\text{CoolFactor})(\text{Days})/(\text{Tanker Capacity})$$

and

$$\text{Fuel Used} = \sum (\text{Qty TAMCN})(\text{PEO})(\text{HPD}_{\text{Heating}})(\text{GPH}_{\text{Heating}})(\text{HeatFactor})(\text{Days})/(\text{Tanker Capacity})$$

Where: Qty TAMCN – TAMCN equipment quantities

PEO – Percent Equipment Operating

$HPD_{Cooling}$ – Hours per Day Equipment is used for cooling and non-temperature dependent PEIs

$HPD_{Heating}$ – Hours per Day Equipment is used for heating-related PEIs

$GPH_{Cooling}$ – Fuel consumption rate in Gallons per Hour for cooling

$GPH_{Heating}$ – Fuel consumption rate in Gallons per Hour for heating

CoolFactor – The portion of a month that cooling was required based on average temperature and desired temperature for temperature-dependent PEIs

HeatFactor – The portion of a month that heating was required based on average temperature and desired temperature for temperature-dependent PEIs

Days – Period the calculation covers, a scalar value

Tanker Capacity – Fuel tanker capacity (can be modified for various capacity)

The $HPD_{Cooling}$ and $HPD_{Heating}$ values for the ECUs, H-45 “pot belly stove” Space Heater, and solar-powered ECU systems reflected the potential hours per day of use based on production duration of the available cooling and heating systems. ECUs can provide heating as well as cooling. The heating capability of an ECU involves resistive technology – air blown over coils in a manner similar to electric space heaters, albeit at a greater scale. In the study, the ECUs were used for heating for the CE, ACE, and LCE Elements. The H-45 heaters, which burn diesel fuel to produce heat, were used for the GCE. When only the ECUs and H-45 Heaters were analyzed, the HPD value was 23 hours. Twenty three hours allowed for one hour for any preventive maintenance and re-fueling. When the solar alternative was in the analysis, a side analysis was accomplished which factored in solar availability into the cooling HPD values. The temperature for the analyzed month was examined to determine the times, to the level of resolution of hours, that cooling would be required. This was compared to the time that the sun would be 10 degrees or greater in elevation in Kandahar, Afghanistan, sufficient to generate enough power for cooling. The portion of the day, if any, that the solar power was not sufficient was apportioned to the baseline generator-powered ECUs and H-45 heaters. This level of fidelity allowed the fuel demands to be calculated and scaled as required for the electrical PEIs.

Power generation, while not the primary MOE, was computed to assess the available amount of generator power in the AOR as compared to the actual electrical power required. It should be noted that the

generators did not factor into the above electrical (or fuel) demand computations since generators only convert power and are not in themselves a direct consumer of electrical power.

The available power generated was calculated as follows:

Power Generated = ∑ (Qty TAMCN) (PEO) (kW) (HPD) (Generator Load) (Days) / (KFactor)

Where: Qty TAMCN – TAMCN equipment quantities

PEO – Percent Equipment Operating

kW – Rated generator output kWs

HPD – Hours per day of use

Generator Load – User desired generator load

Days – Period the calculation covers, a scalar value

KFactor – A 1000 divisor for kWs. Other denominators can be used as desired.

4.7.3 Vehicle-related Energy Calculations

The Study Team employed a similar methodology to calculate vehicle-related fuel consumption, albeit it with an additional usage factor unique to vehicles, idle time, which clearly has an impact on fuel consumption. The idle time factor is based on an AMSAA study of the use of M916 vehicles in OEF[10]and provided the study with estimates of idle to travel time ratios as well as idle versus travel fuel consumptions ratios.

Vehicle fuel consumption was calculated as follows:

PEI Fuel consumption = ((Quantity * Portion * HPD * GPH * IdlePortion * IdleFactor) + (Quantity * Portion * HPD * GPH * (1- IdlePortion))) * Days / TankerCapacity

Where: Quantity – On-hand quantity of PEI

Portion – Portion of items in use

GPH – Fuel consumption in gallons per hour

HPD – Hours per day of use

IdlePortion – The portion of usage that vehicles are idling versus traveling

IdleFactor - The portion of a PEI’s GPH that is consumed at idle

Days – Period the calculation covers, a scalar value

TankerCapacity – Fuel tanker capacity (can be modified for various capacity)

[10] ASMSA Study M916

4.7.4 Aviation-related Energy Calculations

For the study, aviation-related energy use was based on an average of the reported fuel consumption by the MEF (FWD) from April 2010 to September 2010 and illustrated below in Table 4-1.

Month	Ground Fuel (Gals)	Air Fuel (Gals)	Total Fuel (Gals)
April	2,255,139	1,304,755	3,559,894
May	2,932,828	1,380,584	4,313,412
June	2,890,853	1,389,389	4,280,242
July	2,938,334	1,514,810	4,453,144
August	3,190,117	1,550,171	4,740,288
September	2,723,898	1,503,215	4,227,113
Average	2,821,862	1,440,487	4,262,349

Table 4-1: MEF (FWD) Reported Fuel Consumption April 2010 to September 2010

4.7.5 Parameter Values

The previous section described the study's formulas for calculating energy use in three discrete categories of systems. This subsection describes the common parameters used in the calculations that are not specific to an individual PEI.

Additional features were added so that the user could set any number of parameters and select the exact case desired. Various parameters can be modified, and units of measure set. The values used in the analysis are shown in Table 4-2 and described next.

Parameter	Value	Description and Explanation
Over X Days	30	The number of days the fuel usage scaled (in this case, scaled to a month)
Tanker Capacity	4800	The average tanker capacity
Generator Load	0.75	The average electrical load on a generic generator
Generator Efficiency	0.2459	The average generator efficiency among the on hand, deployed generators
kW BTUs	3412	The number of BTUs contained in a kW·h
Diesel BTUs	138700	The number of BTUs contained in a gallon of diesel per hour
Min Desired Temp	70	The ambient temperature below which would require heating
Max Desired Temp	76	The ambient temperature above which would require cooling
Vehicle idle portion	0.76	The percentage of vehicle operation spent idling. 1.0- this factor is the time spent traveling
Idle to Travel GPH	0.1873	The ratio of idle GPH to travel GPH.

Table 4-2: MPEM Parameters

Each analysis period covered 30 days of fuel requirements. A 30 day month was used to remain consistent and provide an equal basis for comparing monthly data.

The tanker size of 4800 gallons is based on the effective capacity of the Marine Corps MK970 tanker, and is used as a common point of reference for the primary MOE for this study.

The generator load that is in the upper range prevents generator inefficiency and maintenance problems. This analysis used 75% as its generator loading which is within the generator's technical operational range. While it

has been reported in the MEAT report among others, that the generators in the AOR are operating at very low loads (down to 30%), the study assumed that the generators would be used more efficiently per the MEAT recommendations[11].

The generator efficiency of 0.2459 is based on the deployed, on-hand quantities of generators in Afghanistan. The efficiency considered the number and types of generators and their individual efficiencies operating at a 75% load.

The $BTUs_{kW \cdot h}$ and $BTU_{Diesel \cdot h}$ values of 3,412 and 138,700 respectively are the theoretical BTUs contained in 1 kW of electricity and one gallon of diesel[12]. These values, along with generator efficiency, were used in the conversion of kW·h to and from GPH of diesel.

Min Desired Temp – The average ambient temperature below which heating would be required.

Max Desire Temp – The average ambient temperature above which cooling would be required.

Vehicle Idle Portion – The portion of the HPD that vehicles are idling versus in travel. The value of 0.76 is based on the AMSAA study for vehicles deployed to Afghanistan.

Idle to Travel GPH – The ratio of fuel consumed in GPH at idle to fuel consumed in GPH at travel speeds. The value of 0.1873 is based on the AMSAA study for vehicles deployed to Afghanistan.

The analysis examined four 30-day timeframes throughout the year. These timeframes were centered on the following solar events indicated in Figure 4-4.

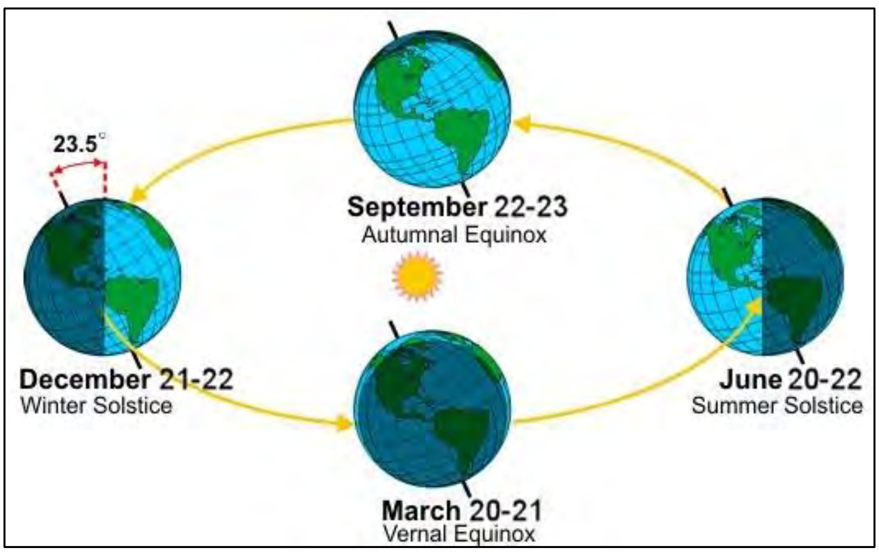

Figure 4-4: Illustration of Solstices, Equinox' and Timeframes[13]

[11] Marine Energy Assessment Team (MEAT) Report, December 2009, Released January 2011 http://dodenergy.blogspot.com/2011/02/meat-report-on-table_9401.html
[12] Department of the Interior, BTU Conversion Table, http://www.doi.gov/pam/eneratt2.html

These events represented timeframes that required extensive heating or cooling as well as a mixture of heating and cooling during the same day. The study used a naming convention that identified each timeframe by the month containing the majority of the days for the period. For example, the 30-day period centered on the winter solstice is referenced as December.

4.8 Scheme of Analysis

The base case for this analysis includes the current ECU suite, as specified by the EDL.

An initial excursion investigated the impact of a 15% more efficient suite of ECUs and an alternate energy case. However, based on guidance from the initial IPR, the experiment was adjusted to include three different ECU efficiencies plus an alternative energy case, for a total of four alternatives. The alternatives are:

- Current ECU suite with 10% increase in efficiency
- Current ECU suite with 20% increase in efficiency
- Current ECU suite with 30% increase in efficiency
- Current ECU suite augmented with solar-powered systems

The following subsections describe in detail the setup of the base and alternate cases.

4.8.1 Base Case

The base case considered the capabilities and energy requirements of the current ECU suite as accounted for in the MEF (FWD) EDL. This ECU suite comprises the following PEIs with their associated TAMCN:

B0003 - AIR CONDITIONER, HORIZONTAL, 1.5T, 60HZ, 18K BTU

B0006 - AIR CONDITIONER, MCS VERTICAL, 400HZ, 36K BTU

B0008 - AIR CONDITIONER, 5T, 60K BTU

B0014 - ENVIRONMENTAL CONTROL UNIT, HORIZONTAL, 36K BTU

B0018 - INTEGRATED TRAILER, ECU AND GENERATOR

B0074 - AIR CONDITIONER, MCS HORIZONTAL, 60HZ, 9K BTU

The Study Team assigned a usage rate of 23 HPD to the ITEG PEI rather than the durations from the BFRS analysis which ranged from 4 to 12 HPD.

[13] Image courtesy NOAA

4.8.2 Alternate Cases: More Efficient ECU Suite

The alternate cases positing a more efficient ECU suite produced the same output in BTUs as the base case (current ECU suite) with reductions of 10%, 20% and 30% in the energy (fuel) required by generators to support this level of production.

The updates were made in the final data sheet to easily identify that the changes were due to the alternative being assessed rather than changes in the original data. Since the ECU was a one for one replacement of the current ECU with a more efficient ECU, there were no changes required to the inventory levels. BTUs produced for cooling and heating remained the same as the current ECU baseline case.

4.8.3 Alternate Case: Solar-powered Augmentation of ECU Suite for Cooling

The Study Team developed a hypothetical alternative case that augmented the current ECU suite with a solar-powered ECU system capable of producing 36,000 BTUs to be used for cooling. The replacement was not a one for one exchange due to the singular BTU rating of the solar version (36,000 BTUs).

Augmenting ECUs with a solar-powered ECU was a multistep procedure. The Study Team first took the number of ECUs in theater as a given, assuming that this quantity was necessary to generate the number of BTUs required in theater. Based on this quantity of ECUs, a computation of the capacity of BTUs was made. The number of solar-powered ECUs was matched to the BTUs assumed required in theater. The BTUs calculation was not dependent upon the HPD or PEO. The number of solar-powered ECUs was based on the quantity of each type of ECU deployed in theater, and their cooling BTU ratings. This calculation was done for each separate element of the MAGTF.

4.9 Additional Analysis Methodologies

The solar-powered alternative case posited augmentation of the existing ECU suite with additional PEIs. Consequently, with these additional systems come requirements associated with moving them into theater and operating them in the field. The study methodology accounted for these requirements by evaluating the impact of mobility in terms of additional airlift assets associated with deploying the augmenting systems and the impact of employment in terms of the additional square footage necessary to set up and operate the augmenting systems.

4.9.1 Mobility Impacts

The mobility impacts were estimated by determining the of number airlift assets required to deploy the alternatives to the AOR.

As with the energy consumption analysis, the baseline case was the ECUs in the EDL. The various alternatives (10%, 20% and 30% more efficient ECUs and the solar-powered ECUs alternative) impacts on airlift are described here and in more detail at Section 5-9. This estimation assumed that the ECUs would be shipped over by airlift and would use the standard 463L pallet unless the loads were over- or out-sized.

The loading of ECUs and required equipment was a manual that process only considered the footprint and weight for loading the 463L pallets. The pallets were then fit into three airlift aircraft: C-130, C-17, and C-5. The pallet loading constraints used are shown in Table 4-3. The baseline case is the reference airlift requirement case. Since the more efficient ECU alternatives were assumed to have the same form, fit, factor, it's understood that it

would have no impact. The solar-powered ECUs alternative is an augmentation capability and would have mobility impacts. The MOEs used for this analysis were C-130, C-17, and C-5 loads.

Airlift Pallet Constraints	Pallets	Max Height
C-130	6	96”, 76” for position 6
C-17	18	96”
C-5	36	96”, 70” for positions 35-36

Table 4-3: Airlift Constraints

4.9.2 Employment Impacts

Employment impacts for the alternatives of this study were limited to a physical lay down of additional equipment employed. The MOE was the square foot area required to employ the alternatives over the current requirement. Again, the baseline ECU case is the reference. Since the 10%, 20% and 30% more efficient ECU was assumed to have the same form, fit, factor, as the EDL ECUs it’s envisioned that there would be no (additional) employment impact.

The Solar-powered ECUs use panels that are packaged and shipped in sets of two panels. The case aids in the protection of the panels as well as providing structural support when they are deployed. A case weighs 103 pounds, which would require a 2-man carry. MIL-STD 1472D specifies a maximum of 82 pounds for a 1-man carry.

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5 Task 3b: Analysis and Results

5.1 Fuel Usage by Equipment Category

Figure 5-1 below is a face validation of MPEM OEF energy calculations and compares favorably to an average month from the MEF (FWD) fuels report. The fuels report breaks out aviation and ground data, but does not delineate between vehicles and electrical energy demand (annotated by the fade across red and blue).

It is important to note that the value reported as MPEM results for aviation fuel consumption during the months of Mar, Jun, Sep, and Dec is based on this fuels report (1.4 million gallons per month) and not calculated according to MPEMs algorithm. The Study Team chose to use the reported value because, as discussed earlier in subsection 4.7.4, further disaggregated aviation usage data was not available and the focus of the study – the impact of efficiency gains from ECU systems – did not require a higher level of resolution. However, should this data become available and/or the focus of USMC analysis involve energy consumption by aviation systems, a methodology to calculate aviation usage on a par with ground vehicle and electrical system usage is easily adapted from the existing MPEM formulas.

Consequently, the Study Team is sufficiently satisfied that the MEPM model provides credible results when compared with real world values.

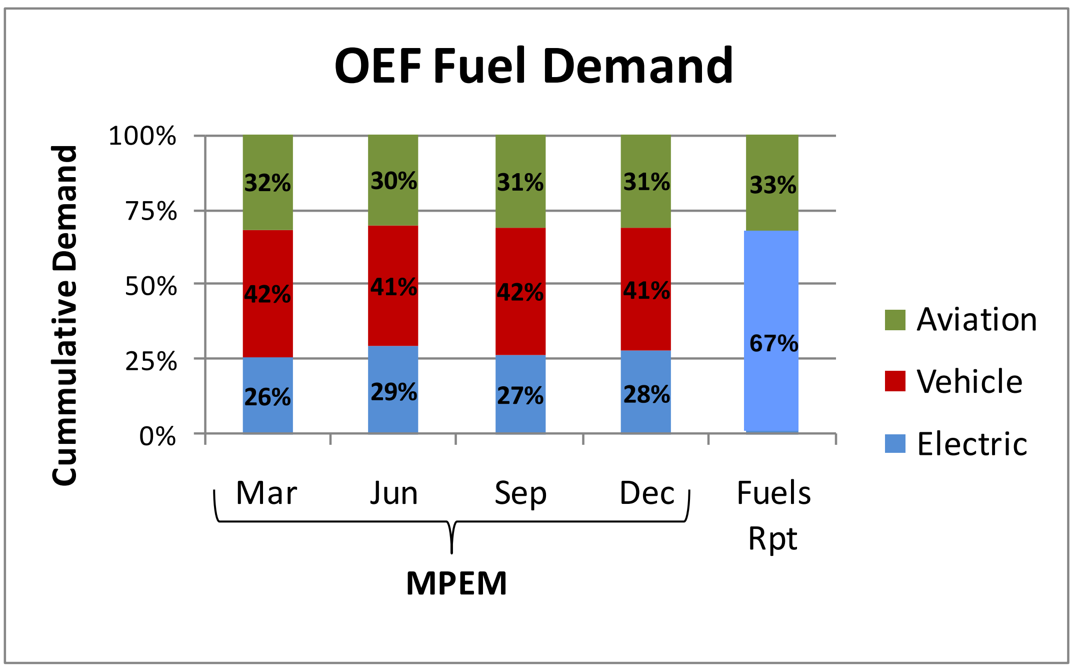

Figure 5-1: MEPM Results, Fuel Usage by Equipment Category

MPEM results for the four months reported varied depending on how temperate or extreme the ambient temperature was. For example, high average temperatures in June require cooling even into the night. March and

September are more temperate. They do not always require heating or cooling, whereas December requires constant heating.

5.2 Contribution of ECUs to Theater-wide Energy Demands

This study focused on establishing the contribution of ECUs in the context of overall theater-wide energy demands. Figure 5-2 below illustrates that fuel consumption – and therefore energy demand – associated with ECUs is indeed significant.

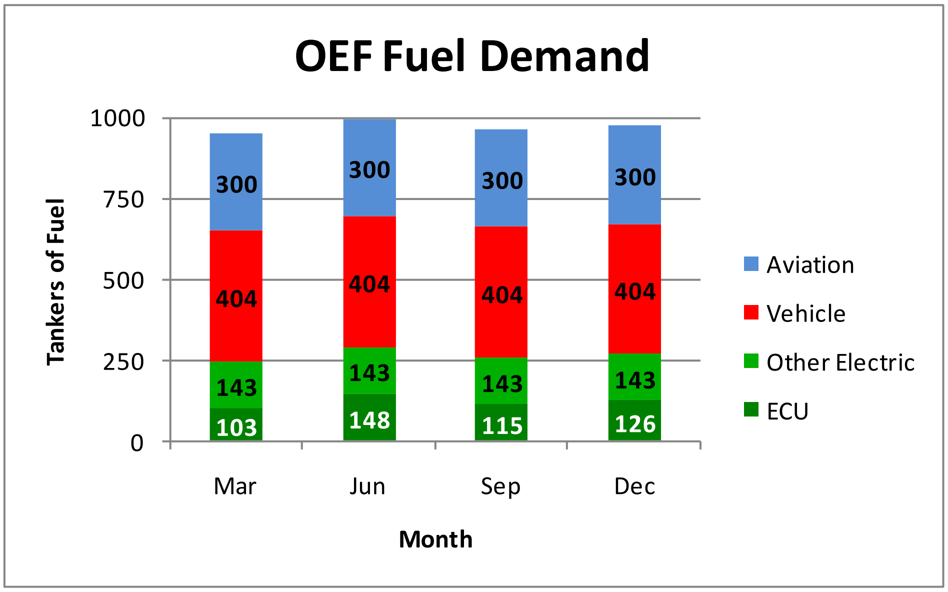

Figure 5-2: MEPM Results, Fuel Usage within Electrical Category

ECU energy requirements average 13% of the total fuel demand across the theater, and 46% of the electrical demand.

5.3 Comparison of Base Case and Alternative Case Results

Figure 5-3 below shows the energy requirements, in terms of tankers of fuel, calculated in MPEM for the base case and the three alternatives involving increased efficiency from the current ECU suite.

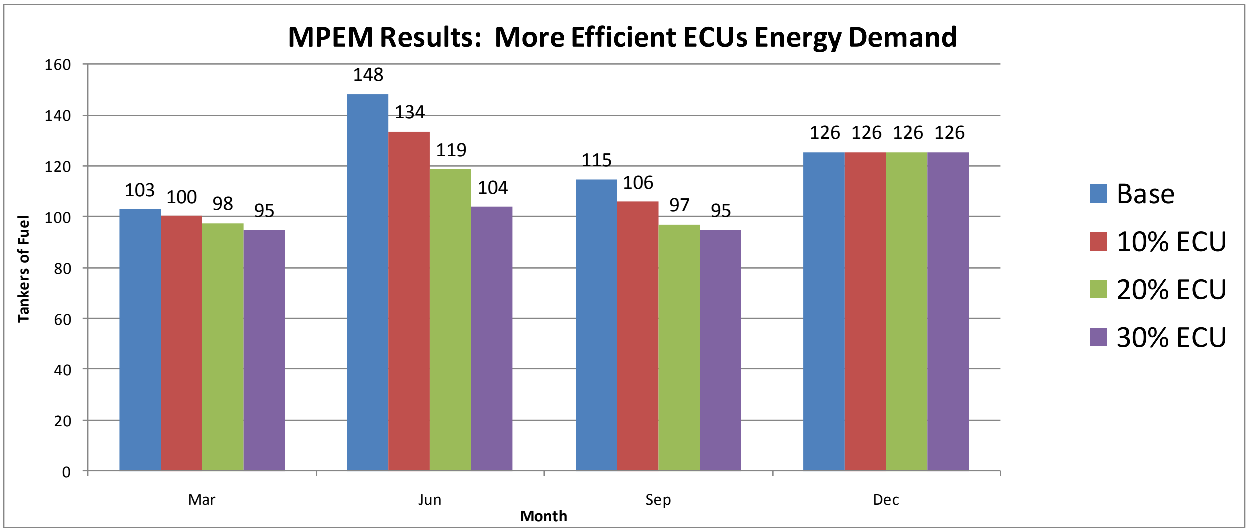

Figure 5-3: MEPM Results, ECU Energy Demand Trends

From these figures, the effectiveness trends of increasingly more efficient ECUs can be seen and understood. This graph shows that when the ambient temperate is high and more cooling is required, there is greater potential for efficiency to be realized. When the ambient temperature is temperate or cold, there is less or minimal potential for cooling efficiency available.

Since efficiencies in ECUs affect only cooling in these alternatives, efficiencies are not realized in December, which requires only heating (thus December's values do not change). ECU efficiencies have a small impact in March, which requires only minimal cooling. September requires more cooling, and June requires only cooling. Thus, the impact of more efficient ECUs is greatest during the month of June.

5.4 Solar-powered ECUs augmentation Energy Consumption

Figure 5-4 (below) expands on Figure 5-3 by adding the solar-powered ECUs alternative. From this figure, the potential impact of solar cooling can be understood to be significantly greater than that of the more efficient ECUs alternatives.

The solar alternative has no effect in the month of December, because the ambient temperature in the month of December requires only heating, and the solar-powered ECUs solution only provides a cooling capability (thus December's values don't change). The relative impact of solar increases in March, September, and is greatest in June, when the most cooling is required.

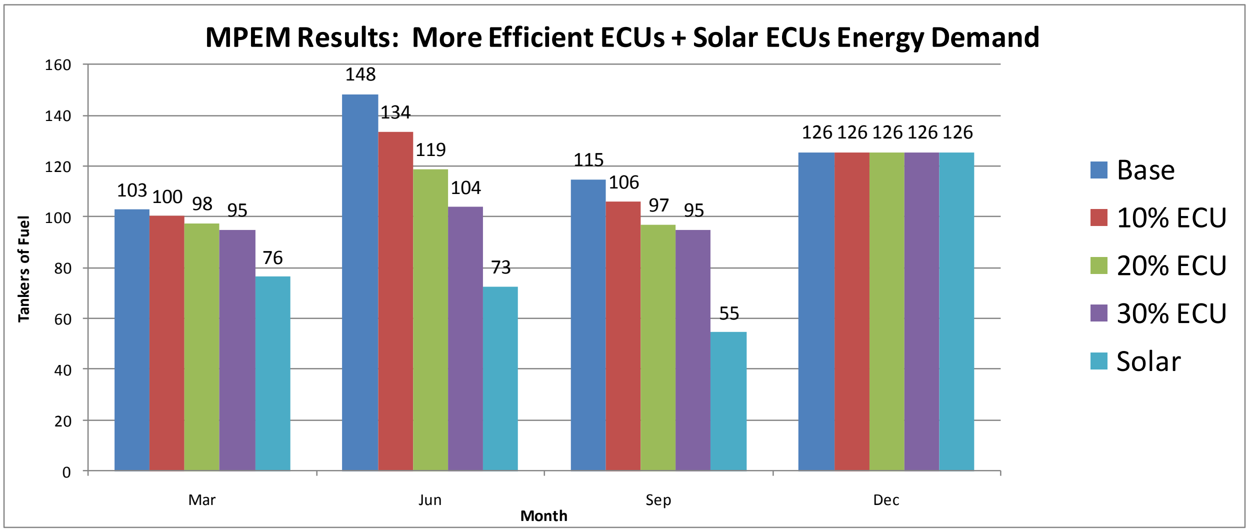

Figure 5-4: MEPM Results, ECU Energy Demand Trends including Solar-powered ECUs

5.5 Annual ECU Energy Consumption

The analysis time periods for this study have been centered on the solstices and equinoxes, which represent the extreme solar conditions (shortest and longest periods of daylight throughout the year as well as the two equal points).

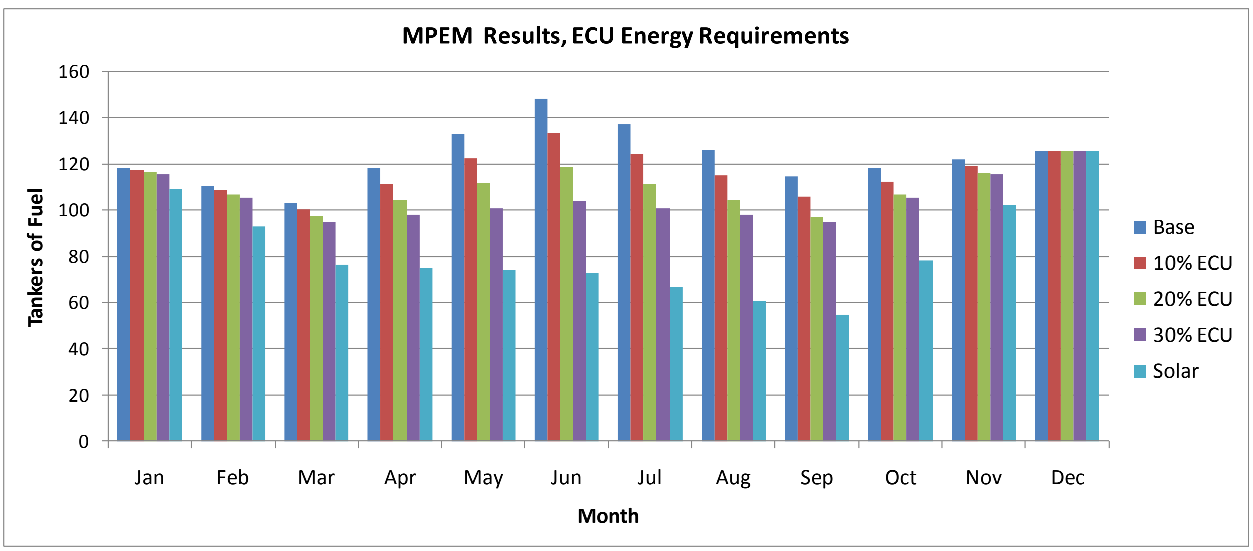

Figure 5-5: MEPM Results, ECU Energy Requirements

Figure 5-5 shows the linear interpolation of the solstice/equinox-related timeframes to establish the values for an entire year.

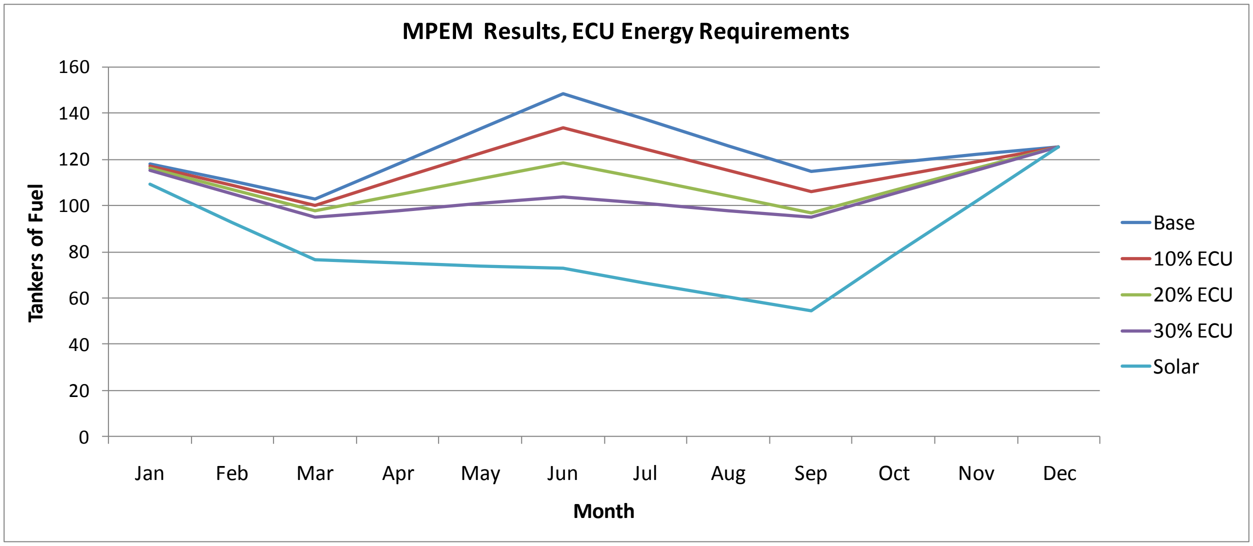

Figure 5-6: MEPM Results, ECU Energy Requirements

Figure 5-6 displays the same data from Figure 5-5 as a line graph and demonstrates the linear interpolation used between the MPEM model results of, Mar, Jun, Sep and Dec. The left side of Figure 5-7 below sums the monthly data in Figure 5-5 to estimate the annual fuel requirements. The right side of figure 5-7 shows the mirror equivalents indicating savings, denominated in tanker equivalents, for each case.

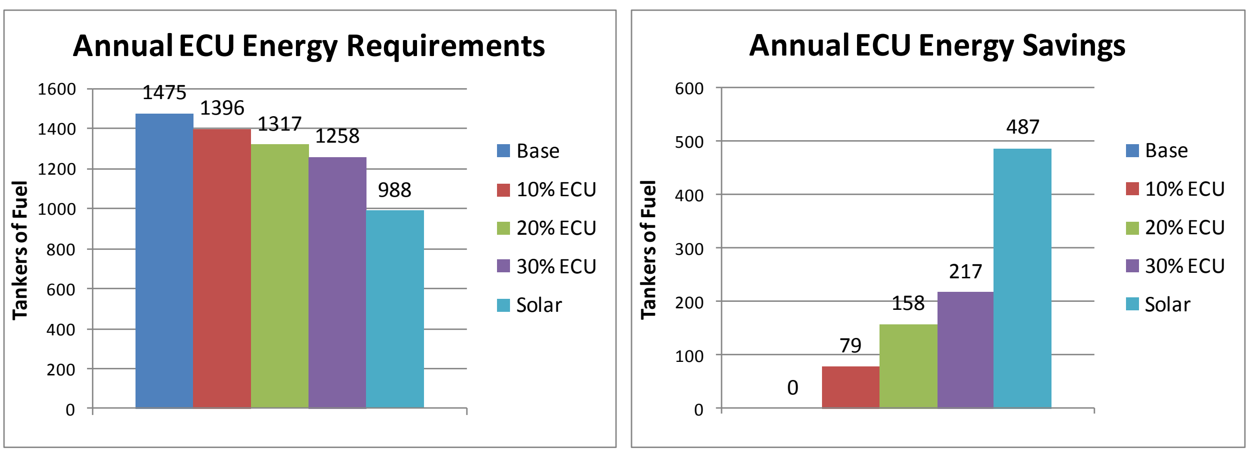

Figure 5-7: MEPM Results, Annual ECU Energy Requirements and Savings

The right side of Figure 5-7 clearly shows that the solar-powered ECUs alternative saves more than twice as much fuel as the 30% more efficient ECUs.

5.6 Annual Energy Savings

Figure 5-8 illustrates the relative costs of fuel at the Strategic, Operational and Tactical level based on a Program Assessment and Evaluation (PA&E) calculation.

Figure 5-8: Strategic, Operational and Tactical Cost of fuel

The Defense Energy Support Center (DESC) sets the rate of fuel at the strategic level of $2.19. The cost to purchase the fuel from DESC and have it transported to a main base camp (e.g., Camp Dwyer) is contained in what is termed the operational level price, and is approximately $6.39 per gallon. The Tactical cost of fuel is also known as the "fully burdened cost of fuel." Various figures for this cost estimate exist, and can vary wildly based on the remoteness and risk of a location.

The cost of fuel at the Strategic level ($2.19/gal) could be recouped by the Marine Corps if it was known that this fuel would not be required. However, this issue is much more convoluted at the Tactical Level. Because of the complexity and uncertainty regarding operations transporting fuel to remote units, it is not only difficult to account for how fuel moves, but also difficult to determine who was involved in transporting it (Army, Contractors or Marines). For these reasons, it is not practical to expect the Marine Corps to recoup the tactical cost for fuel saved in theater. Reducing fuel to remote locations undoubtedly has the effect of reducing operational burdens, yet it is difficult to imagine that any fuel reductions could or should be mapped back to a cut in USMC force structure.

The cost of fuel transported to and purchased at a Main Base Camp is well understood, and could be recouped. This value at the operational level ($6.39 per gallon) can be used to calculate the potential savings that could be recouped from the annual operational fuel budget and applied to more energy efficient solutions, per Table 5-1.

	Annual Fuel Savings in Tankers and Dollars			
	10% ECUs	20% ECUs	30% ECUs	Solar ECUs
Tankers of Fuel	**79**	**158**	**217**	**487**
Savings (Millions)	**$2.42**	**$4.85**	**$6.65**	**$14.95**

Table 5-1: Annual Fuel Savings in Tankers and Dollars

These savings estimates could be understood as an investment incentive for pursuing the various energy efficiency alternatives. The total amount of the incentive should be based on the number of years the Marine Corps is willing to wait before financially recouping on their investment. However, the operational benefits of employing any higher efficiency approach are immediate upon fielding.

It is important to note that these savings are implied, not certain. They are in essence gross estimates, not net estimates, the latter accounting for the costs associated with developing, purchasing, operating and maintaining more efficient ECUs. It was beyond the scope of this study to establish these costs. For solar-powered alternatives, there are also additional costs to be considered in establishing any net savings. These costs stem from the requirement to deploy additional systems into a theater and to accommodate the additional space for their operation in the field. The Study Team performed some first-order estimates to support an eventual determination of these costs.

5.7 Mobility Impacts

5.7.1 Mobility Impacts of Alternative Cases More Efficient ECU

The Study Team modeled the 10%, 20% and 30% more efficient ECU alternatives identically to that of the current (base case alternative) suite of ECUs. These ECUs were provided the same quantity of heating and cooling BTUs as the current ECUs, but did so at 10%, 20% and 30% less energy consumed. This was modeled as a 10%, 20% and 30% reduction in the kWs consumed as well as a 10%, 20% and 30% reduction in diesel equivalent consumed. The updates to the ECU to make it more energy efficient did not change the BTU ratings nor the form, fit, or weight. Thus, there were no shipping impacts.

5.7.2 Mobility Impacts of Alternate Case Solar Power ECU

The solar-powered ECU excursion was modeled as an additional set of ECUs to augment the current suite of diesel generator powered ECUs. As described in the previous results section, the solar-powered ECUs would not replace the diesel powered ECUs. Solar panels would be shipped to theater in specialized photovoltaic (PV) cases. Table 5-2 below shows the shipping size and weight requirements for a single solar-powered ECU system modeled on the SunDanzer system.

Solar-powered ECUs Component								
End Item	Size in Inches	Cubed Feet	Systems Quantity	Weight	System Weight	System Cube Feet	Total Weight Tons	Total Cubed Feet
DC ECU Unit (2 ea)	48 x 24 x 38 ea	25.33	2	195 lbs	390 lbs	50.66	277.3	72,048
PV Case (12 ea)	66.9 x 31.1 x 5.4	6.50	12	103 lbs	1236 lbs	78	878.8	110,947

Table 5-2: Solar-Powered ECU Shipping Size

The solar-powered ECU components are not outsized or oversized and could be configured onto standard 463L pallets. Equivalent aircraft loads were estimated. Twelve solar-powered ECU units could be loaded onto a 463L pallet. While the solar-powered ECU units could be stacked three high, they are stacked two high due to a 96 inch height constraint. Additionally, some loading aircraft locations have as low as a 76 inch height constraint. Figure 5-9 shows the layout of the solar-powered ECU units on a pallet. The solar-powered ECU units weigh 2340 pounds and are 76 inches in height, in addition to the 2.25-inch pallet height.

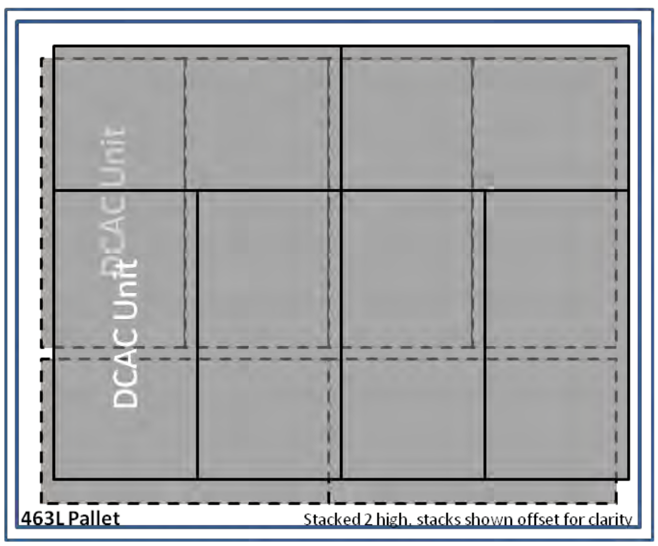

Figure 5-9: DC ECU Loading on a 463L Pallet

The PV cases were also loaded onto a 463L pallet. Forty-three PV cases, each case containing 2 PV panels, would fit on a pallet. The PV cases would only be stacked one high, weigh 4429 pounds, and are 66.9 inches in height. The layout is in figure 5-10 below.

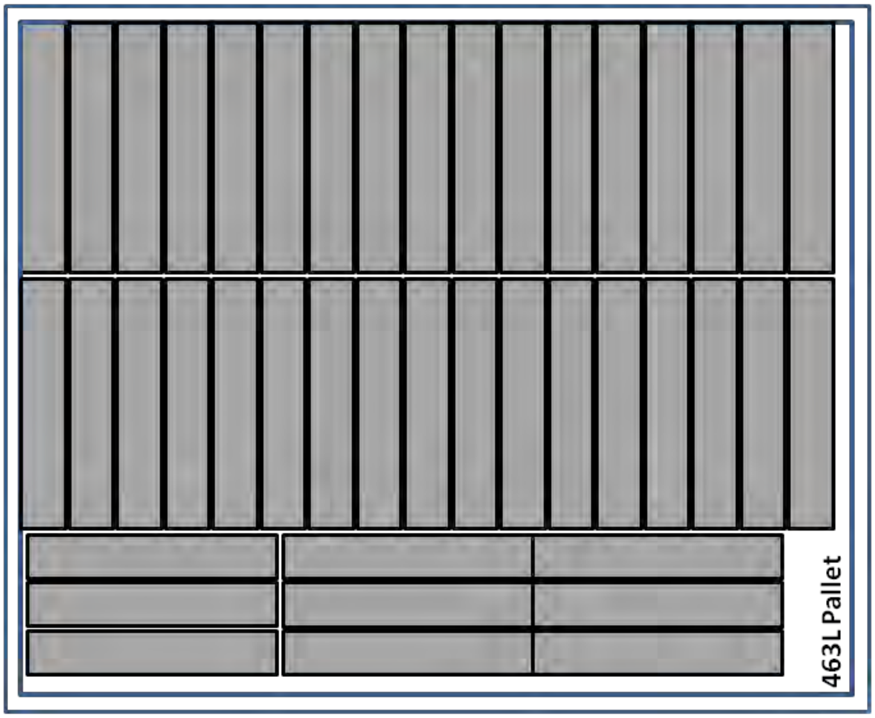

Figure 5-10: PV Loading on a 463L Pallet

The equivalent loads for various military airlift aircraft were estimated against the solar-powered ECUs and PV case requirements. Standard loading configurations were assumed. While mixed loads of solar-powered ECU pallets and other items could occur, loads dedicated to the solar-powered ECU equipment were assumed. The aircraft load equivalents, assuming aircraft-specific height and weight constraints are not exceeded are shown in Table 5-3 below.

Solar-powered ECUs Component	463L Quantity	C-130 Loads	C-17 Loads	C-5 Loads
463L Pallet Capacity		6	18	36
Solar-powered ECUs Unit	238	40	14	7
PV Case	397	67	23	12
Solar-powered ECUs System	635	107	37	19

Table 5-3: Mobility Load Equivalents

5.7.3 Employment Impacts

The solar-powered alternative case requires space to deploy the ECU and a set of solar panels. The solar panels could be deployed in multiple configurations depending on the terrain, foliage, and nearby construction. The panels require a clear line-of-sight to the sun. This unobstructed view also requires that there be no interference from other panels within the array. The analysis assumed a 10-degree minimum elevation angle. This requires either a 676 ft^2 for option A or 493 ft^2 for option B areas for the solar panels. The physical arrangements for option A and B are shown below in figure 5-11 and 5-12, respectively.

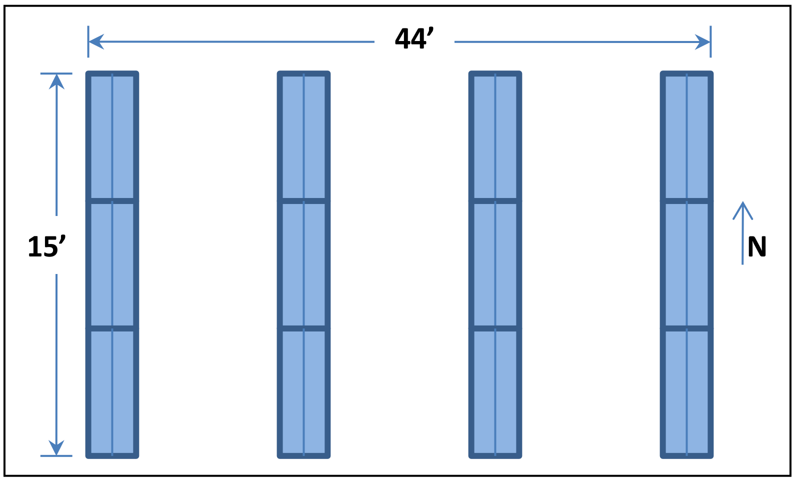

Figure 5-11: Solar Panel Deployment Option A

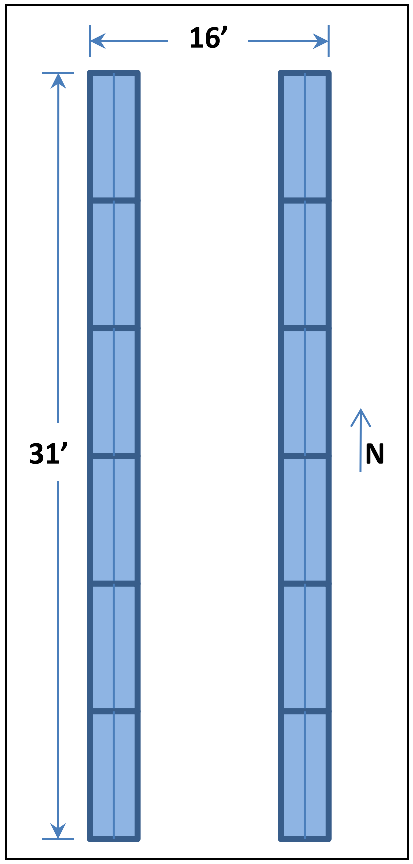

Figure 5-12: Solar Panel Deployment Option B

Table 5-4 below shows the comparative total area required for the two configurations.

[redacted]		
Option	Total Units	Total Area Ft^2
A – 4 x 3 array	1,422	960,690
B - 2 by 6 array	1,422	701,416

Table 5-4: Total Area Required for Solar Panels

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6 Results

A summary of the results from this study is shown in the table below.

	Savings in Tankers and Dollars, Aviation Loads			
	10% ECUs	20% ECUs	30% ECUs	Solar ECUs
Tankers of Fuel	**79**	**158**	**217**	**487**
Savings (Millions)	**$2.42**	**$4.85**	**$6.65**	**$14.95**
C-17 / C-5 Loads	**n/a**	**n/a**	**n/a**	**37 /19**

Table 6-1: Annual Fuel Savings in Tankers and Dollars

The savings in dollars is calculated based on an operational cost for fuel of $6.39 per gallon.[14] The study was not scoped to research and document the technical challenges and associated costs of realizing the postulated efficiency gains of the alternatives. As such, the reported cost savings do not reflect the potential for a net return or loss on investment in the development and fielding of the alternatives. However, anecdotal evidence provided to the Study Team by the E2O suggests that:

- a 10% increase in efficiency from the current ECU suite would require only a nominal investment to achieve and that this level of efficiency gain is technically feasible;
- a 20% increase in efficiency from the current ECU suite would likely require a sizeable investment to overcome the associated technical hurdles; and
- a 30% increase in efficiency from the current ECU suite would certainly involve significant costs and might not be technically feasible.
- The augmentation of the current ECU suite by solar-powered systems obviously entails costs to purchase, deploy, operate and maintain additional systems.

[14] Towards Developing "Fully Burdened Costs", Randal T. Cole, Edward R. Blankenship (HQMC P&R, PA&E), January 2010, CNA

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7 Conclusions

Given the current cost of fuel, there is a clear implication for USMC savings with increased ECU efficiency in Afghanistan. The technological feasibility of the ECU efficiencies that can be achieved is unclear. Further exploration will be required to balance savings against investment. Any projected savings will vary based on scenario and theater. Although there are significant potential savings associated with the implementation of solar-powered ECUs in Afghanistan, they must be weighed against other operational costs. This includes increased transportation to deploy and either redeploy or transition in-country, as well as account for, an increased footprint on bases where solar panels are employed.

MPEM is face validated and could be used to examine other aspects of USMC energy footprint and consumption.

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8 Observations

In the course of the study, the Study Team encountered several challenges as well as insights into the energy context. From that exposure, several observations were collected. They are described below.

8.1 Accurate Energy Consumption Data is Limited and Hinders the Analysis, Planning, and Assessment of Energy Usage.

8.1.1 Improved data accuracy

The study required kW ratings for the electrically powered PEIs. For some items, the ratings provided from TFSMS were not consistent with the equipment type and description. For example, a Camera Suite, A0152, had a 60 kW peak power requirement even though the system was a handheld digital camera and a laptop computer with a draw of 0.25 kW. Numerous other systems had incorrect power data as well and various sources were used to adjust those values. The Data_Updates tab, in each of the model runs files, contains the updates made. In order to assess the power requirements and impacts, accurate data is required for the systems under study.

It is assumed the data that the study used is the same that other USMC systems use for deployment planning, fuel planning, and usage assessments. Incorrect and limited data can affect those systems as well.

8.1.2 Usage Auditing

The specifications and requirements data are useful in planning and research. However, actual usage provides the essential feedback for adjusting the factors relating to how the equipment is used. The usage capability should be minimally invasive to operations and not affect the mission. During design and development phase, knowing what information is required and in what format the can aid the capturing of the usage data with minimal effort. This data can then be relayed back to a central system that can gather and catalog it and distribute it to other data systems and studies.

8.2 System energy requirements are limited

8.2.1 Improved resolution of electrical power specifications

While the study refined electrical kW values, those given, researched, and utilized was a single value. However, a single kW ratings could represent a system in nominal use, heavy use, standby, or charging, or most likely starting up (often requiring a “peak power” surge power requirement). Separate power rating values for a defined set of normalized states would greatly aid this and similar analyses as well as fuel and deployment planning.

8.2.2 Expanded vehicle usage specifications

The vehicle fuel consumption data from the BFRS was a single value representing travel usage. The HPD factors were by Combat Element and phase. These factors are important and useful. However, expanding data to include when the vehicles are at idle vs. traveling and the commensurate change in fuel usage would also aid fuel consumption analysis fidelity. These specifications could be expanded to include road, terrain type or vehicle use. Vehicle uses would be appropriate to the specific vehicle such as MRAP on various missions, fuel tankers

loaded/unloaded or grading operations for graders. This data could be captured by additional vehicle logging efforts similar to, but expanded beyond, what AMSAA has already undertaken.

8.2.3 Expand electrical usage specifications

Projected or planning aviation usage data exists in terms of sortie duration and sorties per day. Similar, limited vehicle HPD data exists, but similar electrical usage data is not available. Useful electrical usage data includes the expected portion of equipment in use and the HPD of expected use. The hours per day of use would also consider the state of the equipment described above (e.g., standby or nominal use). While these factors would aid in fuel usage analyses, they could also aid in the specification development. This data could be captured by electrical logging efforts in theater.

8.2.4 Include energy as a system requirement

System requirements for ECUs, as well as other items, have Key Performance Parameters (KPPs) that are relevant to the primary purpose of the item and requirements for other system capabilities. Energy use or requirements are not commonly set as requirements beyond what may be in standard military specifications documentation or industry standards. Explicit energy consumption requirements in each of the appropriate operational modes could aid in reducing the energy footprint as well as in planning and operating energy use.

Currently, MCSC does not have a formal requirement for a more energy efficient system. Including energy requirements and proposals addressing how to meet them will enable those factors to be considered during the system selection process. While energy efficiency requirements may increase initial acquisition costs, lower direct and indirect operational costs may be realized.

8.3 E2O Energy Study was a first order assessment

8.3.1 Power Distribution and Layout

This study aggregated the electrical power requirements and capabilities into a single value. This value did not consider the geography nor distribution points. Where equipment is located and how it is tied together would increase the fidelity of the equipment—even without a dynamic, moving scenario in play. Including the Lines of Communication (LOCs) in the geography would also increase the fidelity of a fuel distribution model. However, adding geographical and power distribution layouts might not provide any useful resolution for current analysis requirements.

8.4 Generator and Solar-Powered ECU heating capability could provide heating efficiencies

This study examined the benefits of more efficient ECUs as well as solar-powered ECUs. However, these systems only affected cooling capabilities. It could be possible to have ECUs that can provide heating similar to residential heat pumps. The fuel benefits of that heating capability were not assessed and the costs and effects of such a capability are unknown.

Appendix A **MPEM Users Manual**

Please double-click on the box below to view the User's Manual for the MAGTF Power and Energy Model.

MPEM Users Manual

MAGTF Power and Energy Model

Version 1.8.2

15 July 2011

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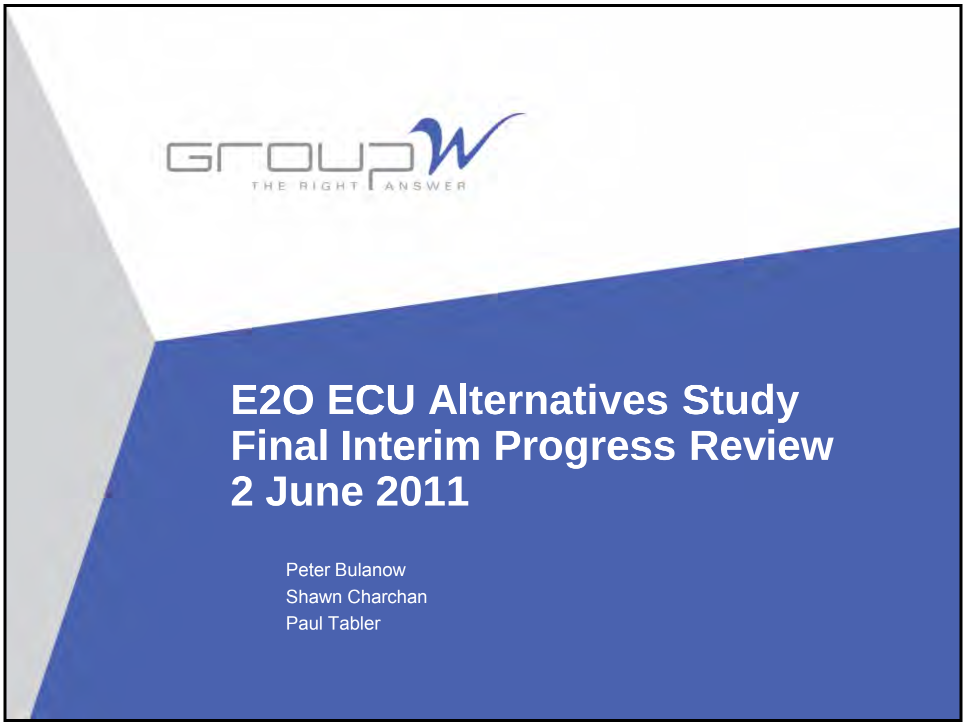
Appendix B IPR Slides

Please double-click on the image below to view the Final IPR slides.



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Appendix C – Acronyms

Acronym	Explanation
ACE	Air Combat Element
ADP	Assured Delivery Price
AOR	Area of Responsibility
AMSAA	Army Materiel Systems Analysis Activity
BFRS	Bulk Fuel Requirements Study
BTU	British Thermal Unit
CE	Command Element
CMC	Commandant of the Marine Corps
CNA	Center for Naval Analyses
COAST	Current Operations Analysis Support Team
DC	Direct Current
DESC	Defense Energy Support Center
DOD	Department of Defense
DOS	Days Of Supply
E2O	Expeditionary Energy Office
ECU	Environmental Control Unit
EDL	Equipment Density List
EPS	Expeditionary Power Systems
ExFOB	Experimental Forward Operating Base
FBCF	Fully Burdened Cost of Fuel
FBCW	Fully Burdened Cost of Water
FOB	Forward Operating Base
GCE	Ground Combat Element
GPH	Gallons Per Hour
HPD	Hours Per Day
IED	Improvised Explosive Device
IPR	Interim Progress Review
ITEG	Integrated Trailer-ECU-Generator
KPP	Key Performance Parameter
kW	Kilowatt
kW·h	Kilowatt hour
LCE	Logistics Combat Element
LOC	Lines of Communication
MAGTF	Marine Air-Ground Task Force
MCCDC	Marine Corps Combat Development Command
MCSC	Marine Corps Systems Command
MEAT	Marine Energy Assessment Team
MEF	Marine Expeditionary Force
MOE	Measure of Effectiveness

MOP	Measures of Performance
MPEM	MAGTF Power and Energy Model
MROC	Marine Requirements Oversight Council
OAD	Operations Analysis Division
OEF	Operation Enduring Freedom
OIF	Operation Iraqi Freedom
OIF	Operation Iraqi Freedom
ONR	Office of Naval Research
PA&E	Program Assessment and Evaluation
PEI	Principle End Item
PEO	Percent Equipment Operating
PV	Photovoltaic
SEER	Seasonal Energy Efficiency Ratio
SME	Subject Matter Expert
SMP	Sustain the Mission Project
TAMCN	Table of Authorized Material Control Number
T/E	Table of Equipment
TFSMS	Total Force Structure Management System
TQG	Tactical Quiet Generator
VAC	Volt Alternating Current
VBA	Visual Basic for Applications
USMC	United States Marine Corps
UTR	Unit Table of Equipment (T/E) Requirement